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ARI TECHNICAL REPORT
TR-77-A21

EXPLORATORY EXAMINATION OF PURGE TECHNIQUES

by

John J. Saalberg, James R. Miller,
Terry L. Friesz, and Carol A. Keegan

SCIENCE APPLICATIONS, INC.
1911 North Fort Myer Drive
Arlington, Virginia 22209

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NOVEMBER 1977

Contract DAHC 19-76-C-0050

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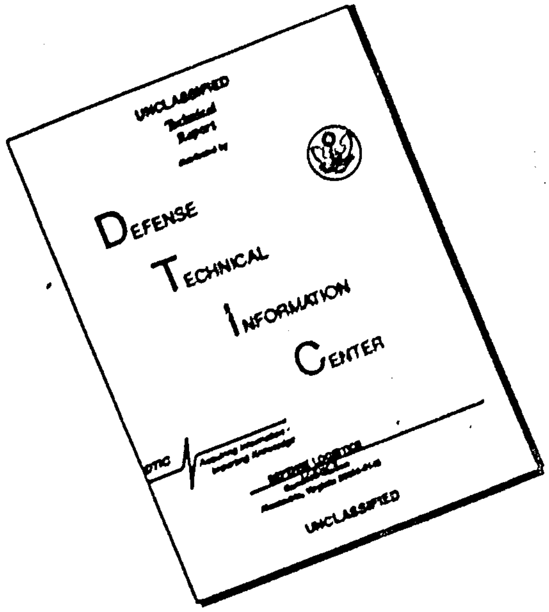

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18 19 ARI

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TR-77-A21	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER 9
4. TITLE (and Subtitle) 6 Exploratory Examination of Purge Techniques.		5. TYPE OF REPORT & PERIOD COVERED Final Rep[redacted]t, 15 Sept 76 - 15 Jul 77,
		6. PERFORMING ORG. REPORT NUMBER 14 SAI-78-614-WA
7. AUTHOR(s) 10 John J. Saalberg, James R. Miller, Terry L. Friesz, [redacted] Carol A. Keegan		8. CONTRACT OR GRANT NUMBER(s) 15 DAHC 19-76-C-0050 new
9. PERFORMING ORGANIZATION NAME AND ADDRESS Science Applications, Inc. 1911 North Fort Myer Drive, Suite 1200 Arlington, VA 22209		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 16 2Q762722A765
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Research Institute for the Behavioral and Social Sciences 5001 Eisenhower Avenue, Alexandria, VA 22333		12. REPORT DATE 11 Nov[redacted] 1977
		13. NUMBER OF PAGES 154
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 155p.		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Technical guidance provided by Dr. A. F. Fields of the Battlefield Information Systems Technical Area of the Army Research Institute

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Purging and Prepurging	Tactical Operations System (TOS)	Decisionmaking
Storage Overload	Essential Information	Daisy System
System Overload	Decision Assumption Measurement	RADCOL System
Information Overload	Cost Effectiveness Analysis	Smart System
Communications Overload	Cost Benefit Analysis	(continued)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The problem of overload in tactical information systems can be reduced by purging--freeing a tactical data base of useless, redundant, outdated, and incorrect information. Technological changes in ground combat and in information acquisition and handling have created the requirement for an automated Tactical Operations System (TOS) for command and control, and established a need for purging. This report analyzes the role of information in decisionmaking and examines techniques for identifying a decisionmaker's information needs.

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407 154

19. Key Words

Data vs. Information
Multiattribute Analysis
Multiobjective Analysis

20. Abstract

Current purging procedures and division level informational needs for land combat are reviewed and potential criteria developed for identifying information essential for task performance in the Division Tactical Operations Center. Rules, techniques and operative procedures are suggested which can be employed to manage and control TOS data.

Purging procedures employed with manual files or written records are not directly adaptable to automated systems, although such procedures provide precedents which can aid in establishing suitable methods for purging automated systems. The computer industry has not focused upon purging as a problem. However, a number of available computer science techniques can help meet purging needs. A number of existing quantitative methods can be used to evaluate purge technology innovations. New innovative methods are required for managing combat information in automated systems at Army Division level to prevent overload and to improve control and direction of engaged forces.

Foreword

The Battlefield Information Systems Technical Area of the US Army Research Institute for the Behavioral and Social Sciences (ARI) does research on the psychological process underlying the proper judging of tactical intelligence, information system resource management, the use of automated tactical data systems and staff aids to battle management in command/control systems, intelligence, and target acquisition as well as on tactical information systems--the transformation and organization of battlefield information, the man-machine interface with tactical information, and the management of information flow. The present report reviews techniques of purging--freeing tactical data bases of useless, redundant, outdated, and incorrect data--to reduce the problem of overload in tactical information systems.

Research on information management in tactical systems is directed by ARI through contracts with organizations selected for their unique capabilities and facilities for research in tactical information systems. The present research was conducted by personnel of Science Applications, Inc. of Arlington, Virginia, under contract DAHC 19-76-C-0050, with the technical guidance of Dr. Alison F. Fields of ARI. This work provides part of the necessary technological base for research leading to solution of operational problems. It was done in response to requirements of Army Project 2Q762722A765 and with special interest from the US Army Combined Arms Combat Development Activity (USACACDA), Fort Leavenworth, Kansas.

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Chapter 1

THE IMPACT OF TECHNOLOGICAL CHANGE AND THE NATURE OF INFORMATION USE

1.1 SCOPE OF PAPER

Modern managers are increasingly confronted with growing quantities of records, data and information in both digital format and hard copy files. These documents normally contain the substance and rationale of past actions and the detailed information needed for institutional or functional decision and for operational direction of activities. While increased amounts of information should, in principal, contribute to better decisions and more rational management, excessive quantities of data can overload an information system and make the decision process cumbersome and inefficient. Thus, many contemporary managers (including military commanders) are faced with a problem reducing the volume of existing records to preserve or improve operational efficiency. This problem applies to both manual and automated records and information.

Management and operational information normally has a measurable effective life span during which content value is comparatively high. After passage of some period of time records begin to loose value, ultimately becoming of little use except for historical purposes. As this occurs the problem of records disposal grows in importance. Sperfluous records and information can be handled in many different ways depending upon the nature and size of the office or activity involved, and upon the type, scope and quantity of information. Records with little residual value can be removed from active files and migrated to less accessible storage locations or media; those no longer of use can be destroyed. Segregation and disposal itself can be based upon a variety of criteria such as record age, content or frequency of use, and the process of identifying and disposing of material can be performed manually or automatically in the case of computerized information systems. Such procedures and methods for managing the quantity of material held and processed in a given information system bear many titles, such as records retirement, records disposal, file maintenance, etc. For the purpose of this analysis, however, the authors have termed all activity undertaken to limit the flow of data into a given information system or to remove extraneous data from such a system as "purging".

The paper explores in general terms those rules criteria, techniques and operations that can be applied to purging to insure retention of optimum information data sets for specific purposes by identification and retention of "essential" information and elimination of superfluous material. Focus, however, is upon the application of purging to information management at Army division headquarters level. Thus, drawing upon existing literature in computer science, psychology, and information science, and from knowledge gained through visits to various military and non-military command and control and management centers, current state-of-the-art in purging is discussed and its appropriateness for use with the automated information Tactical Operating System (TOS) within the Tactical Operations Center (TOC) of U. S. Army combat divisions evaluated. The paper begins with a brief discussion of those technological changes that have created the requirement for automated information handling systems for direction of ground combat and aggrevated the purging problem, and examines the role of information in decisionmaking. Chapter II explores psychological techniques that can be employed to help identify a decisionmaker's informational needs. Current state-of-the-art in purging is discussed in Chapter III. Divisional level information needs for land combat are analyzed in Chapter IV, and criteria are developed for essential information needed for task performance in the division TOC for that facility to function effectively. This leads to the identification of those information elements which can be completely purged from TOS proper and those which can better be moved to a slower storage medium for reacquisition, if necessary. General rules, techniques and operative procedures are then suggested which can be employed to manage and control TOS data and which can serve as a point of departure for subsequent development and testing of specific detailed procedures in a field environment. Methods for evaluating purge procedures are analyzed in Chapter V and an evaluative process is developed to assist in selection among purging alternatives.

1.2 RESULTS OF IMPROVED COMMUNICATIONS

Until the twentieth century, ground warfare was usually waged with only generalized direction from the national level. This situation has changed drastically during the past fifty years. Improved electronic communications and associated innovations have had a profound effect upon the ability to control and direct modern military forces.

Instructions can now be rapidly transmitted immense distances at the speed of light and great quantities of data and amounts of information can readily be exchanged between force elements, between operating units and controlling headquarters, and between national authorities and forces in the field. As a consequence, centralized direction of tactical engagements has become a reality.

Such improved communication is not an unmixed blessing, however. Though centralization carries the promise of more rational and prudent force direction, it holds the threat of over control and excessive supervision at operating level. Too much detailed information at the top can easily encourage excessive meddling; and a case can be made that the ease of transmitting information frequently creates an appetite for data at all headquarters above the operating level without regard to whether or not such information can actually be managed, used, or is even necessary for decision or action at a given command. Conversely, ease of communication facilitaties the provision of large amounts of diverse information from national level agencies and sources to field tactical headquarters directing military operations and even to engaged units themselves. Such information, when current and accurate, can have appreciable intelligence value and be extremely useful at Corps and Division level for planning future operations and analyzing near-term enemy intentions. However, such information can become a burden if security considerations are excessively difficult at operating level or if the quantity passed to field agencies is so large that the small staffs and limited automated support in the tactical headquarters are innundated and cannot sift the information received quickly or efficiently enough to identify specific items that have real value. In this respect, facile communications have created needs for new information handling techniques to screen, prepurge or synthesize information at the national level before transmittal to the field. A similar though less extreme problem may also be created by the excessive detail (quantity) of information provided from maneuver elements to field headquarters.

1.3 EFFECTS OF SENSOR DEVELOPMENT

Paucity of enemy information, formerly the rule in battle, also no longer applies. Development of numerous types of highly sophisticated sensors -- photographic, electro-magnetic, seismic, etc. -- and the aircraft and satellite platforms to carry or implace such devices make it possible for field commanders and national policy formulators to collect in real, or near real time, immense amounts of data relating to an opponent's physical presence, activity and intentions. Large numbers of such sensor devices presently exist and are being employed in indications and warning activities. Existing sensors are being continuously improved, and suchdatatems proliferated driven by the premise that "more information is always better". Until recently, little attention has been given to the synergism of complementary systems and the way in which information from various sources might be fused or evaluated concurrently through comparative analysis.

Unless precautions are taken to filter sensor data, existing systems can innundate a tactical command headquarters. Mindful of this, sensor or sensor platform managing agencies normally process and reduce sensor acquisition data before passage or delivery to military commanders or policy formulators. In theory, only essential information is passed to the commander and this, in turn, transmitted to him as quickly as possible within a prescribed time window that will permit rational reaction to that information. Careful delineation of the timeframe within which information can be employed for a given purpose or decision sets the procedural bounds and dictates functional decentralization and a subdivision of labor. Despite this, however, more information is frequently available than is needed or can be effectively employed, and the commander's staff is normally faced with the problem of disposing of that data which is not of immediate use.

1.4 INFLUENCE OF AUTOMATIC DATA PROCESSING

The electronic computer, with a capability to store immense amounts of information and quickly retrieve selected items, does not provide the universal solution to the problem of information management. All too frequently, data processing is harnessed to an information handling task without full appreciation of the human and material costs involved in data capture. This is particularly true when input data is acquired from a large number of sources and must be manually entered into computer memory. Further, the ease with which the computer can recall such information tends to encourage an appetite for excessive detail whether or not such detail is actually needed. Unless information can be quantitatively analyzed or graphically aggregated, information retrieved from an automated system in alphanumeric form must be read by the recipient -- a process which compels the user to be highly selective in recalling information and slows his cognitive process of assimilating and using information to reading speed. Even when the computer is harnessed only to a task of automatic transmission and rapid distribution of textual messages, little is gained in an operative environment if the information is delivered in such large quantities that examination and evaluation is not possible within reasonable periods of time, or if critical information cannot be readily identified.

1.5 FACTORS CONTRIBUTING TO DATA PROCESSING SATURATION

Almost every major Army ADP and communications system has a built-in potential for overload. This can develop in the form of communications and information processing channel saturation and/or through the filling of all available data storage capacity. Such overloads can occur periodically under routine peak processing loads or when extra information processing is required to support some type of exercise, or when unexpected heavy demands develop during actual crises or combat operations. Unfortunately, procedures for procuring and using Army ADP frequently set the stage for future overload. For example, since computer hardware and software represent a major capital investment even in an environment of sophisticated weaponry, ADP systems are often scaled down in procurement design until approved systems meet only minimum requirements. In addition, Army ADP managers are strongly encouraged to make maximum use of the available ADP hardware. Thus, there is usually a steady growth in the number and size of applications placed on fielded systems and in the frequency of processing such applications. This process of stimulated growth steadily erodes whatever excess capacity or cushion was purposely provided for the user in the original design concept. However, the extra capacity serves as the ADP manager's only reservoir on which he must draw to satisfy unexpected demands on his ADP system. Significantly, once the cushion of excess capacity has been lost there is very little that the data manager can do in the short run to enhance processing capacities without selectively reducing service to customers.

A number of major factors can contribute to overload and saturation. These include:

- an increase in data processing requirements volume resulting from changing organization activity levels;

- the capacity or volume constraints of the communications and ADP hardware configurations dictated by military specifications, such as limited available space in vehicles or shelters;

- the tendency to load the information processing system with less important applications in order to improve average system use during low activity periods; and

- an inability of the managers and other system users to make the hard decisions necessary to purge or limit the amount and kinds of data held in computer memory.

Most ADP systems have periods of overload when unexpected demands arise. The immediate impact of overloads is delay in reports and/or reduction in the accuracy of reports as a result of the inability to perform timely data base update and file maintenance. Ironically, interviews with data managers indicate that delays generated by these temporary overloads are not always an unwelcome occurrence. For example, personnel in the New York City Police Department view this condition as a buffer which prevents additional work requirements from being passed on by operating elements of the police force. As the level of work declines, delayed reports are then produced, the backlog of work eliminated, and the system returns to normal schedule. Such a delay can have a serious effect upon the decision process if alternative methods of obtaining required information are not possible. Of importance, however, is the early recognition that delays experienced during peak levels of routine processing can be of great consequence during crisis or actual combat. Of course, the seriousness of the problem is compounded if the crisis or combat operation extends over a protracted period.

Data managers generally tend to use the capabilities and capacities of their system to satisfy as many needs of the parent organization as possible. Thus, applications grow in number and processing increases with the passage of time. This tendency to fill available capacity results from the desire to automate administrative tasks saving manpower costs, and the need to demonstrate productive use of an expensive system. Part of the rationale for placing lower priority applications on Army ADP systems is that such routine use will partially offset the acquisition and maintenance costs during non-crisis conditions. Implicit in such rationale is the belief that the less important applications will be removed from the system when the additional capacity is required. In most cases, however, automation of a manual function results in gradual withering away of unused skills and ultimate loss of the ability to perform the administrative task manually. As an example, forms used in manual processing can be exhausted or misplaced and the persons who know the manual methods can be lost through normal personnel rotation and attrition. Thus, the ADP manager finds himself with no alternative but to continue processing low priority jobs on the computer system during times of crisis because of the inability of functioning agencies to obtain necessary information in any other way.

The tendency to include complex capabilities that will satisfy every possible demand that can be placed on the system further complicates the development and use of ADP for battle support. So important are the decisions which must be made during a crisis situation and in combat that pressure is almost overwhelming to provide the manager with a system which can support every conceivable information requirement. This, despite the fact of general recognition that specification of all relevant information requirements is an unattainable goal.

1.6 TOS CONSTRAINTS AND INFORMATION MANAGEMENT PROBLEMS

Development of an automated TOS to manage information for command and control of group operations at Army Division level faces comparatively unique and difficult constraints. For survivability in a tactical environment, the physical location of the Division TOC must be concealed. This restricts the size of the entire facility and dictates that any automated system which the TOC contains also be limited in size. However, informational loads with which such a system will most likely have to deal are large. In the event that Soviet or Warsaw Pact forces are engaged, large enemy force elements will probably be involved and a rich enemy target array presented on the battlefield. Not only will the quantity of information relating to enemy force disposition and location be substantial, but the mobility of opposing forces will make this information highly dynamic and rapidly perishable. Yet, given the nature of modern land warfare, time windows for decision at Division level frequently are quite short. As an example, for effective target acquisition and engagement, such windows can be as small as 3 to 5 minutes when enemy activity involves moving vehicles or 15 to 20 minutes when a nuclear delivery system is involved. Thus, quick system response is essential. All this presents rather conflicting design parameters. TOS must be small in size and rugged in construction, yet it must be capable of quickly handling large informational loads with a small number of operators and a minimal support staff. This poses a real danger that such a limited system will rapidly become saturated in a combat environment unless superfluous information is quickly removed or purged from the system.

Saturation of TOS will occur if one or more of four essentially different but interrelated conditions develop. If the amount of data entered into the system completely fills main memory storage and the associated disks and tape drive, a condition of storage overload will prevail. If the data holdings become so large that critical information cannot be retrieved efficiently and reliably within acceptable time limits, system overload will occur. This particular overload results simply because the machine itself can perform only a finite number of functions within a given period of time. Each process involves some shifting or manipulation of data, and although processing time is brief, the data input and data output processes are slow by comparison and result in retrieval and update queing. When holdings are inordinately large, the bulk of data is held on secondary storage medium which requires further time for data search, acquisition and movement to main memory before processing. A condition of communication overload can develop at the interface point between external communications links and the computer system in the data entry process. This condition will result either when much more data is received than can effectively be placed in the system within an acceptable timeframe, or when more data is generated than the external communications system itself can accommodate and move to the processing site. For TOS, this will most likely occur at a point of man-machine interface, although not necessarily at the computer itself. Finally, whenever the computer has available and provides more information than the user can deal with effectively, information overload will occur. Unlike storage overload and system overload, which are failures within the computer system proper, information overload also occurs externally at the point of man-machine interface while the system operator is attempting to retrieve information previously entered into the computer. Analysis in this monograph examines "purging" as a method for coping with these four overload problems.

1.7 PSYCHOLOGICAL CONSIDERATIONS ASSOCIATED WITH DECISION-SUPPORT DATA BASES

Relationships between the type and quantity of information which an individual or a functioning agency requires for sound decisionmaking and judgment is central to the entire issue of purging. With this in mind, some fairly intuitive characterizations of an adequate decision-support data base can be made without lengthy exposition on the psychology of decisionmaking. An effective data base is one that is relevant to the decisionmaker's information-seeking objectives, composed of timely, comprehensive and accurate data which is minimally redundant, and which is efficiently organized for rapid and correct retrieval of information requested by the user. Conversely, an inadequate data base contains an unacceptable amount of irrelevant, outdated, incomplete, inaccurate, redundant, and/or inefficiently retrievable information.

Such intuitive characteristics, however, fall short of providing adequate definition for terms like "relevant", "timely" and "efficiently organized". To explain these terms more precisely and derive conclusions about optimal purging techniques, it is helpful to examine the psychological literature for empirical evidence of relationships between the characteristics of an information set supporting a decision, and the parameters of the decisionmaking process performed by the user of the information set. This permits identification of those particular characteristics of the data base (e.g., content, frequency of update, retrieval techniques, etc.) which can be systematically associated with patterns of decisionmaking behavior evidenced by users of the data base (e.g., amount of information considered before the decision is reached, confidence in the final decision, accuracy of the final decision etc.). It also facilitates identification of those data base characteristics reliably associated more with decisionmaking dysfunctions (e.g., improper interpretation of probabilistic data, prolonged information seeking and inappropriately delayed decisionmaking) than with positive decisionmaking functions (e.g., reduced decisionmaker stress, more timely decisions, and greater user satisfaction with the data base). Such knowledge can contribute directly to a more explicit definition of an adequate data base than can be reached intuitively, and should generate a tentative list of psychological criteria for effective data base creation. Finally, such analysis can provide some measure of the relative importance of various data base features in terms of optimizing the decisionmaking behavior of its users. Before commenting upon this literature, however, it is useful to define explicitly the critical terms, decisionmaking , data and information and to characterize in a general manner the role of information-seeking in the decision process.

Decisionmaking involves several components, each of which bear on the definition of an adequate information system. These include:

- the decisionmaker and his goals;
- the environment or context of the decision problem;
- alternative responses open to the decisionmaker for attaining his goals;
- relative probabilities for successful attainment of goals associated with each alternative; and

- a criterion level for expected probability of success, which prior to the decision exceeds the probability associated with any identified alternative.

Information is factual material useful for decisionmaking which serves to reduce a decisionmaker's state of uncertainty. It adds to his ability to predict events and conse-[illegible]ces of actions associated with the decision environment and [illegible] alternatives. When a decisionmaker is unable to make [illegible]ictions comfortably or effectively he initiates [illegible]n-seeking. Thus, the need for information occurs when [illegible]ionmaker's current level of certainty about important env[illegible]onment objects, states and events exceeds his criterion state of certainty, regarding the probability of success associated with his decision alternatives.

Data Versus Information - Burch and Strater[1] define data as raw, unevaluated facts in isolation which, when placed in a meaningful context using data processing operations, allow the user to draw inferences about subjects of interest to him. Information is composed of data, but data alone are not necessarily information. Information provides the user with an increase in knowledge and it is derived when data elements are properly processed and matched to the user's problem or decision.

The basic purpose of a decision-support information system is to capture and process data in a manner that yields information to the users of that system. Although information is ultimately decomposed into data, not all data are informative, and within a set, all are not equally informative. The primary challenge of the decision-support information system, then, is to extract from an avalanche of data available to an organization those relevant data which decisionmakers require to make an information decision. While the mechanisms for extracting information out of a data set are ultimately data processing techniques, no one data processing method or combination of methods, manual or automated, can guarantee that data will be processed in a manner that completely fulfills the user's information requirements. Determining a decisionmaker's information needs, his definitions of information -- or relevant data -- is an information system design requirement separate from data processing plans and methods.

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[1] Burch, J. C. and Strater, F. R. Jr. Information Systems: Theory and Practice. Santa Barbara, Calif: Hamilton Publishing Co., 1974, pp. 23-26.

1.7.1 Information-Seeking and Decisionmaking

A fuller understanding of information can be achieved by analyzing its role in the decisionmaking process. In fact, some researchers define information totally with respect to its decisionmaking role. Green and Tull[2] use the word, information, to refer to "recorded experience that is useful for decisionmaking". The model below is an attempt to represent the relationship of information-seeking to decisionmaking (See Figure 1-1).

The authors of this model (Burch and Strater)[3] emphasize, however, that theirs is a "rational" view of the information-using process, which assumes total understanding on the decisionmaker's part of his goals and the alternative behaviors open to him. Thus, this model is more rational than actual human behavior both in terms of the manner in which decision-support information is judged relevant, and in terms of the amount of information considered preparatory to a decision. In judgments both of data relevance and allocation of resources to information gathering, human behavior requires explanation beyond that provided by Burch and Strater.

Atkin[4] has developed the following model of information utility which suggests some of the less rational aspects of information-processing during decisionmaking on adaptation of their model presented in Figure 1-2. He sees information-seeking governed by a decisionmaker's subjective estimate of the reward value derived from a message and his estimates of the expenditures required in order to obtain the message. The reward value is composed of both instrumental and noninstrumental utilities of information. Instrumental information explicitly contributes to the decisionmaker's selection of the optimal response open to him. Non-instrumental information has no such direct problem-solving value; however, the decisionmaker may nonetheless be reinforced by seeking and processing it.

A commander's or decisionmaker's need for information is a function of extrinsic uncertainty produced by a perceived discrepancy between his current level of certainty about important events, objects, and states and a criterion state he wishes to achieve before making a decision. A "primitive cognitive

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[2] Green, P.E. and Tull, D.S. Research for Marketing Decisions, 3rd ed., Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1975, p. 11.

[3] Burch and Strater, op. cit., p.54

[4] Atkin, C. Instrumental Utilities and Information Seeking Clarke, P. (ed.). New Models for Mass Communication Research, Vol. II. Beverly Hills: Sage Publications, 1973, pp. 205-242.

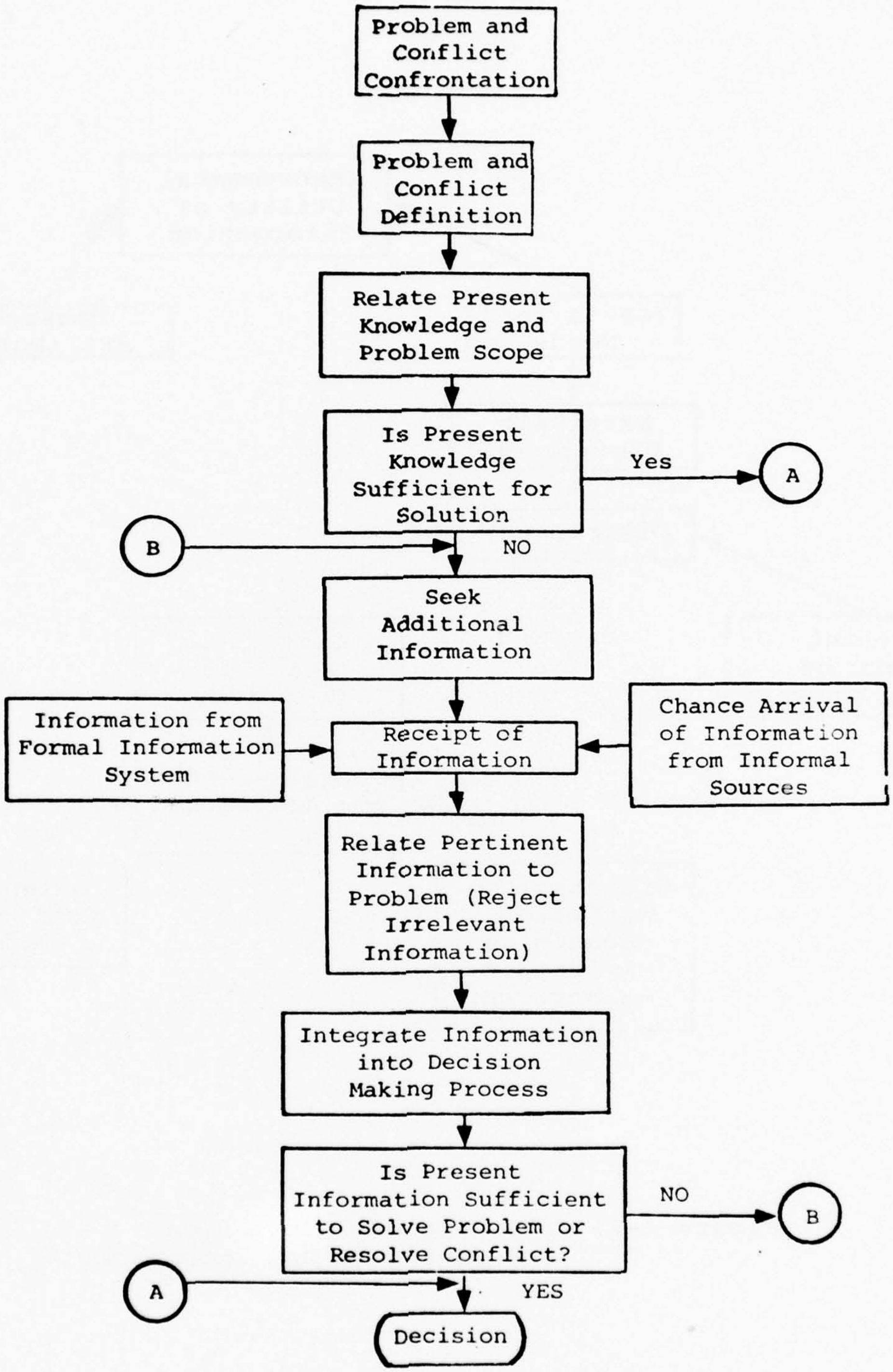

Figure 1-1. Flowchart of the Use of Information in a Decisionmaking Process (Burch & Strater, 1974)

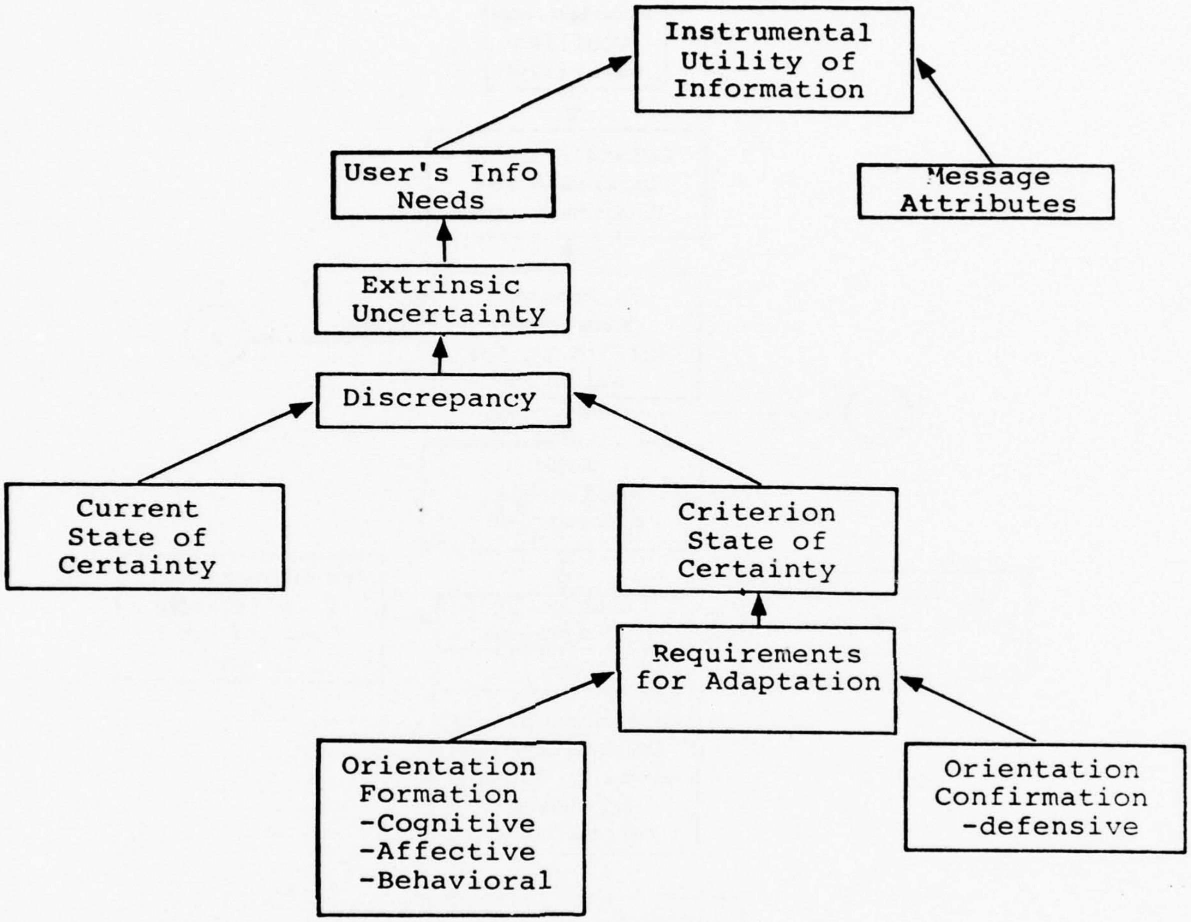

Figure 1-2. The Role of Information Processing in Decisionmaking

uncertainty" arises when the individual perceives an insufficient level of knowledge about an object after reprocessing stored cognitions from previous experience.

Most problem-solving situations involve more complex cognitive processes than a simple gain in knowledge about an object. The individual usually wants to combine cognitions to make a decision and to implement it. A "complex cognitive uncertainty", then, arises when existing cognitions are inadequate for responding to situations that require orientations, decisions or performances involving one or more objects. It is important to distinguish these two types of uncertainty, because information inputs that reduce primitive uncertainty may serve to increase complex uncertainty.

Extrinsic uncertainty encompasses those primitive and complex uncertainty states generated by a lack of knowledge concerning anticipated adaptive responses or psychological adjustments to previous behavioral, affective or cognitive activities. The magnitude of this uncertainty depends on the size of the "knowledge gap" between the current state of certainty and optimum certainty.

The composite judgment of information in terms of its instrumental utility, however, does not adequately explain information-seeking. Noninstrumental information seeking can and does occur even when the decision to be made is clearly defined and instrumental utilities should be easier to judge. In information-seeking, it is not the message content attributes (i.e., their decisionmaking relevance) which initiate and sustain the information-seeking behavior. Rather, information-seeking is based on noninstrumental "process gratifications" in which the information-seeking and information-exposure processes become inherently rewarding, independent of the decisionmaking value of such behavior. In this manner, Atkin suggests a useful distinction between data and information which might be extended to a distinction between "data-seeking" and "information-seeking".

Donohew and Tipton[5] provide additional insights into the role of information seeking, avoiding and processing during decisionmaking activities. Once again, the quirks of human problem-solving do not lend themselves to the kind of rational use of information modeled by Burch and Strater.

First, we are told of individual differences in "information-seeking and processing styles". Individual decisionmakers develop an information handling approach out of

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[5] Donohew, L. and Tipton, L. A Conceptual Model of Information Seeking, Avoiding and Processing in Clarke. op cit., pp. 243-268.

past decisionmaking experiences which controls the selection of information used to cope with current decision requirements. Thus, the specific information sought to support a given decision would vary among individuals as a function of their perception of the decision problem, current knowledge of decision-relevant information, and preferred modes of information input and integration.

Second, across decisionmakers there is evidence of changing values for decision-relevant information at different points in the decisionmaking process. For example, Tipton[6] found a preferred order of information input, in terms of the evaluative power of information as it reflects relative probabilities of success associated with each decision alternative. This apparent preferred order of evaluative information was: neutral information, favorable information, then unfavorable information about alternatives.

Third, Berelson and Steiner[7] note that one longstanding principal in self-selection of information is sheer accessibility; people are exposed to communication to the extent that messages are readily available to them. Indeed, Atkin[8] notes that an important aspect of information processing is "information yielding" which occurs when unrewarding messages are so available and obtrusive that significant expenditures of time, effort or money are required to avoid exposure to the message and yielding becomes easier than avoiding.

Decisionmakers can behave rather uneconomically in their allocation of time and effort to information-seeking. The literature on information closure (the point at which an individual ceases his information gathering preparatory to a decision) indicates that decisionmakers believe it is best to delay closure as long as possible[9] and that they generally seek more information than is objectively required to reach a sound decision[10] Evidence from Stamm[11] suggests that the amount of information acquired is an inverted-U function of the amount of time available for decisionmaking.

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[6] Tipton, L.P. Effects of Writing Tasks on Utility of Information and Order of Seeking. Journalism Quarterly 47 , 1970, pp. 309-317.
[7] Berelson, B. and Steiner, G. Human Behavior New York: Harcourt, Brace and World, 1964.
[8] Atkin, op cit. 1973.
[9] Chaffee, S.H., Stamm, K.R., Guerrero, J.L., and Tipton, L. Experiments on Cognitive Discrepancies and Communication. Journalism Monographs 14 1969.
[10] Edwards, W. Dynamic Decision Theory and Probabilistic Information Processing. Human Factors , 2 , 59-73. 1962.
[11] Stamm, K.R. in Chaffee, et al., op cit. 1969.

Certain aspects of information-seeking for a decision appear more rational, however. For example, delay of closure has also been shown to be directly related to decisional complexity. Lanzetta and Driscoll[12] found that information seeking increased systematically with the degree of decisional uncertainty operationalized as the number and relative strengths of alternatives in the choice situation. Atkin[13] reports that similar studies have also shown that the importance of the decision increases the amount of information-seeking.

However, there is evidence to suggest that these information-seeking behaviors have to be qualified with data relevance considerations as perceived by the decisionmaker. Svenonius[14] suggests these might be a "critical mass" of references retrieved in an automated system -- a number of retrievals beyond which the user says "to heck with it" and terminates his search. Pullen and Hoffman[15] suggest that the size of this critical mass is "probably a weak function of the relevance of retrieved items".

While the Burch and Strater model[16] is very helpful in reflecting upon some of the sources of wide individual differences among decisionmakers in information-seeking behavior, the full complexity of the decisionmaking/information gathering process is de-emphasized. Realistically, complex decision tasks often place an individual in more than one state of uncertainty at the same time. In fact, his sources of uncertainty may be conflicting, complementary, or redundant and it is the combination of these uncertainties that determine the decisionmaker's true information needs.

1.8 DECISIONMAKING CONSIDERATIONS

We have seen that the role of information in a decisionmaking process cannot be totally and objectively defined by decisional requirements. Even where decisions are so clearly delimited that the specific pieces of information needed to optimize the selection of the best alternative can be explicitly

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[12] Lanzetta, J. and Driscoll, J. Effects of Uncertainty and Importance on Information Search in Decisionmaking. Journal of Personality and Social Psychology, 10, 479-486. 1968.
[13] Atkin, op cit., 1973.
[14] Svenonius, E. An Experiment in Index Term Frequency. JASIS, 23, No. 2, 109, 1972.
[15] Pullen, K.A. and Hoffman, C.W. On the Science of Information Retrieval. U.S. Army Ballistic Research Laboratories, Report No. 1896, 1976.
[16] Burch, J.G. and Strater, F.R. Jr., op cit., 1974.

identified, decisionmakers frequently behave in a variety of irrational, counterproductive and sometimes unpredictable ways. These decisional idiosyncracies are primarily a function of personal decisionmaker style, previous experience, and situational variables including fatigue, time pressures and the availability of information. Thus, the following considerations pertaining to the psychology of decisionmaking and related information handling activities appear critically related to the effective design, operation and evaluation of a psychologically sound decision-support data base:

- Even given the same decision situation, individual decisionmakers will vary their information-processing preferences and behaviors in accordance with differences in their perceptions of decision requirements, and of the salience and criticality of the decision problem; with their previous experience with similar decision problems; with their exposure to other sources of information; and with individual decisionmaking biases and styles. While the nature of the decision task does serve to set wide parameters on the definition of relevant data, information needs do not arise exclusively, or even generally, from the nature of the decision situation. The population of decisionmaker users of an information system must be the final source of information about the proper contents of a supportive data base. Decision-support information systems must be sensitive to individual differences in information preferences, allowing for individual information-seeking and valuing, in order to maintain decisionmaker confidence in, and use of, the system.

- The argument that an information system should leniently provide for individual differences among decisionmaker users suggests that data base content parameters should not be drawn too narrowly. However, there is a counterbalancing need to avoid the excessively inclusive data base. The research literature suggest two dysfunctions of an unmanageably large and primarily irrelevant data base. On the one hand, decisionmakers may needlessly prolong data seeking and thereby inefficiently delay the selection of a decision alternative. On the other hand, there is the danger of frustrating searches of a predominantly irrelevant data base leading to a premature termination of the information search and the resulting selection of a decision alternative on the basis of inadequate information.

- The costs of recording and processing data must be weighed against some determination of the value of that data to the decisionmaker. Whereas the cost of providing information to the decisionmaker is a fairly straightforward estimate (i.e., system costs including methods, devices, media and manpower support), information value is an intangible entity and estimates of its magnitude are correspondingly difficult. Furthermore, different users' perceptions of the relevance of the same data can vary markedly even when these data are communicated in the same way, at the same time, and for the same decisionmaking problem, and there is no guarantee that they will use such data in the same fashion. Inasmuch as individual differences among decisionmakers and situational variables must ultimately influence the value of information, criteria for collecting, filtering, prioritizing and retiring data must still be determined.

Modern military commanders frequently receive more than their fair share of information -- in many cases more than they can normally handle. This is equally true of the staffs that support them, and technology appears to be making the condition progressively worse rather than better. Commanders and their staffs must deal with this information under conditions of stress when noise, fatique, lack of sleep, poor food, grinding responsibility, and the threat of failure and defeat sap strength and endurance. Though the vital decisions which these individuals make are based upon the information at hand with its attendant degrees of uncertainty, such decisions also hinge upon more than the available information -- upon those anticipated consequences of choosing one course of action rather than another. Even so, careful determination of the optimum information set for a given decision should improve the probability of correct choice among options. Some methods that can be employed to help determine a decisionmaker's needs are explored further in the next chapter.

Chapter 2

METHODS FOR DETERMINING A DECISIONMAKER'S INFORMATION NEEDS

This portion of the paper briefly presents five general methods which can be employed to help determine decisionmaker information requirements, and summarizes advantages and disadvantages associated with each. All of the examined methods have as a common goal identification of decision-relevant information and are built upon the assumption that the delimiting of information will result in a more effective or timely decision.

The first involves direct questioning of the decision-maker.[1] Specific techniques employed can range from structured questionnaires to unstructured "in depth" interviews. In essence, a decisionmaker is guided into listing his specific informational needs for functional performance and decision. Frequently, critical incident techniques prompt identification of salient information categories. Problems with such a direct approach result mainly from probable biases of respondents. Specification of one's information preferences for a given set of important decisions makes these preferences subject to critical review by peers or superiors. Preconceived notions of "ideal" decisionmaking behavior can and will influence portrayals of actual information handling. Further, information needs related to decisionmaking may be difficult to verbalize, since they involve, in part, unconscious predispositions and habits. Finally, a questionnaire designer or interviewer may impose his preconceptions and biases on the approach to direct measurement of information needs.

A second method involves expert analysis of the decision to be made, and objective development of information requirements for optimal selection of a decision alternative based on experts' experience with the decision task, decisionmaking conditions, criteria and goals.[2] Where decisions are not stereotyped in format and/or are unanticipated, data base composition for decision support can be difficult.

A third method represents a higher order analysis of information requirements established in the second method, and is built around the concepts of "decision situation" and "decision area", were a "decision area" is defined as a group of decisions with common informational requirements, and a "decision situation" represents a higher-level aggregation of decision areas grouped in terms of similarity of decisionmaking goals. Such conceptual organization eliminates duplication of stored information, minimizes system operations costs, reduces data base redundancy, and enhances retrieval efficiency. This particular

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[1] Burch and Strater, op. cit. pp. 121-123.
[2] Burch and Strater, Ibid.

technique has been employed to determine informational needs for decisions relating to resource allocation for the support of Air Force contingency and general war planning.[3] In this case, decision areas included:

- the status of war reserve materiel assets;
- the ability to support unestablished contingency plans; and
- the ability to support established contingency and general war plans.

Informational requirements were logically derived for each of the decision areas (e.g., shortage and overage information). From these informational requirements, data needs were established and a computer algorithm developed to transform data on war reserve material into the appropriate information needed for each decision area. Implicit both in this particular method and in the second method, is the fact that the nature of a decision primarily determines a decisionmaker's requirements. Characteristics of the decision task and of decision areas serve to set wide parameters for appropriate data base content, but will not fully accommodate individual decisionmaker needs and preferences.

A fourth method involves observation and analysis of actual information-processing behavior during an individual or a group's decisionmaking activities.[4] The activity is observed either in the field during actual occurrence or simulated in a laboratory with systematic manipulation of decisionmaking and/or information processing variables. Often, use is made of protocols obtained by tape recording a decisionmaker as he "thinks aloud" during the process. Data gathered includes information input alternatives, the decision alternatives addressed at the time of each information request, and retention/purge decisions about available data where limitations are imposed on decisionmaker's ability to retain acquired information. Analyses focus on content characteristics (e.g., source, time of origination, subject matter) of selected and nonselected information and that retained or purged. Where strong patterning of such decisions emerges, the method can include development of a discriminant function to describe the decisionmaker's information-handling behavior.

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[3] Carlson, A. and Talbott, M., Jr. The WRM Information System Air Force Institute of Technology, Wright-Patterson AFB, Ohio School of Systems and Logistics, June 1976.
[4] Green and Tull, op. cit.

One obvious advantage of this approach is its potential for encouraging user confidence in his data base. If purging algorithms for an information system have developed through modeling of actual decisionmaking and information-processing behavior, user confidence in the probable relevance of the resulting data base should be enhanced. However, significant problems can arise if observer's project their own perceptions of the decisionmaker's information valuing into the analysis. Furthermore, the value of data collected in this manner is highly dependent on the skills of the decisionmaker being observed. The technique is powerful when employed skillfully, but remains more of an art than a science.

A fifth method -- a spinoff of the fourth -- involves the measurement of "decision assumptions". Direct questioning of decisionmakers is avoided and focus centers upon analysis of the decisionmaker's actual behavior with decision support information. This method differs from the preceding method in two important ways:

- First, while the decisionmaker under study is still asked to make a data relevance judgment within the context of a defined decision problem, he is asked to provide additional information about his relative preferences for each piece of information and/or the extent to which different pieces of information are similar or substitutable. The nature and number of comparisons required in this data collection almost always necessitate laboratory gaming rather than field observation methods.

- Second, and most important, the approach does not attempt to discriminate differentially relevant data solely on the basis of its objective characteristics (e.g., source, length, topic) but rather attempts to elicit from the decisionmaker the psychological dimensions along which he perceives these data to be more or less similar, preferred, and relevant.

This final method is aptly described by Wilcox[5] as a search for the assumptions which underlie a decisionmaker's choices among alternative responses, and for the kinds of new information which will cause him to perceive a change in the nature of each available choice. Furthermore, each type of such information gauges some attribute of the choice alternatives. This operational definition of an attribute meets the definitional requirements for information as data useful for decisionmaking, that is, for discriminating among alternative response options.

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[5] Wilcox, J.W., A Method of Measuring Decision Assumptions. (Cambridge, Massachusetts: MIT Press, 1972).

The philosophy behind this approach is that relevant data base content is best determined by an understanding of the decisionmaking rules employed by the data base user in approaching a given decision or set of decisions. Assumptions that guide decisions are said to be only partly conscious, so direct questioning of decisionmakers is ineffective. Wilcox also rejects stereotyping decisions or decision areas because many real-world decisions are necessarily novel or unstructured. Finally, he rejects field observation studies as time-consuming, obtrusive and expensive.

Wilcox further argues that information systems can be optimally designed if one uses measured decision assumptions to match available data to user needs. Such measurement implies discovering attributes associated with alternatives, achieving a preferred rank among all decision alternatives and measuring their relative influence. The preference for one alternative over another is predictable as a function of the alternative's coordinates in a multidimensional attribute space. The method draws on recent work in attitude and opinion research, marketing research and cognitive psychology to measure decision assumptions within a choice-set representation: that is, within a graph linking attribute characteristics of decision alternatives to decision outcomes. In particular, the method combines variations of the semantic differential, multidimensional scaling (MDS), and the Role Repertory Test to determine decision assumptions.

The semantic differential technique consists of asking respondents to rate experimental objects along a large number of relevant prespecified bipolar adjectival scales. Multidimensional scaling methods use comparisons of interobject similarities to construct a spatial configuration of objects in which interobject distances correspond to perceived dissimilarities, and spatial dimensions correspond to significant discriminating concepts for organizing the perceived relationships among objects.[6] Recently, the technique has been reduced to a set of real, positive numbers, specifying interobject distances of all object pairs.

It should be noted that a variety of studies have used multidimensional scaling to determine the dimensions along which decisionmakers characterize a set of objects. Rigney and DeBow[7], for instance, related dimensions used by military officers to characterize simulations of attacks to their threat assessments of such attacks.

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[6] Wilcox, op cit., 1972.

[7] Rigney, J.W. and DeBow, C.H., "Multidimensional Scaling Analysis of Decision Strategies in Threat Evaluation," Journal of Applied Psychology, Vol. 51, pp. 305-310 (1967).

Kelly's Role Repertory Test, originally developed to measure the structure of interpersonal social perceptions, asks the decisionmaker to match a given list of object role descriptions with appropriate objects from his own experience. A limited number of object triads are later presented to him. For each triad, he is to specify which pair of options is most similar. This then identifies the one option that is different in some important way. In the comparison process, the decisionmaker is encouraged to name attributes along which he differentiates the triad members. These data are factors analyzed to eliminate redundancies. In the next stage, the decisionmaker positions each object or each relevant attribute scale previously obtained.

Wilcox's eclectric method draws from the semantic differential, multidimensional scaling and the role repertory test. The decisionmaking task under investigation consisted of stock investment oppotunities and the author sought to uncover the conceptual structure underlying investment decisions so that the information most relevant for such decisions could be identified. The procedure involved personal interview and completion of three questionnaires. Procedures employed were as follows:[8]

- <u>Personal Interviews</u>

1. Decisionmakers were given a list of 20 "roles" that various stocks might have played in the decisionmakers experience (e.g., "a stock sold too soon", "a very popular stock", "a stock whose market action is understood"). The decisionmaker then identified a stock representative of each role.

2. Twenty triads of stocks were composed and presented to the decisionmaker and he was asked to identify attributes along which he discriminated triad members, as described above.

- <u>First Questionnaire</u>

3. The decisionmaker was asked to divide each attribute elicit in the interview into equivalent intervals from 2 to 9. Then appropriate stocks were placed in separate categories depending upon lack of relevance or lack of information. Finally, those remaining stocks were matched with each attribute scale within the appropriate interval.

- <u>Second Questionnaire</u>

4. Decisionmakers were given blank scales for the elicited attributes used above. The scales were divided

[8] Wilcox, op cit., 1972.

into the decisionmaker's previously determined segments. He then placed each of a new list of relatively well known stocks on these scales or in the two "not relevant" or "not enough information" categories. All decisionmakers received the same list of stocks.

- Third Questionnaire

5. The decisionmaker rated the same standardized list of stocks in terms of an investment objective he selected. After a few months, a fourth and fifth questionnaire repeated the second and third questionnaire for a similar standardized list of stocks. This repetition was designed to gather validity data.

Data collected in this manner allowed a test of the hypothesis of measurement procedures that was used to predict decisionmaker's subsequent ratings. Thus, one first estimated relationships between each decisionmaker's ratings of stocks along various attributes and the ratings of the same stocks along his own investment objectives. These estimated relationships were then tested for validity with the new data obtained in the last two questionnaires.[9]

In the stock market study, the procedure was shown to have "modest" predictive validity, with a wide range of ability to predict individual decisionmaker choices. The applicability of such a procedure to military decisionmaking remains to be tested. The method deserves study, however, since it embodies a comprehensive attempt to override measurement difficulties associated with the four more general methods discussed earlier in the chapter. Furthermore, the method is specifically designed to establish information collection, management and, evaluation guidelines for the manager of a decision-support data base.

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[9] Wilcox, op cit., 1972.

Chapter 3

PURGING -- CURRENT STATE-OF-THE-ART IN PURGING PROCEDURES AND RELEVANCY TO TOS

Prior to discussion of specific state-of-the-art procedures for purging, the reader will be provided with a background of the sources of the information upon which the findings of this study are based. This background will be followed by an introduction to the current problems and trends in methodologies for computer purging, and finally, the remaining sections will discuss specific procedures which may have utility in resolving subsystem or system purging requirements. This chapter is organized around the following sections:

3.1 BACKGROUND - This section describes the sources information of supporting problem definition and the selection of purging methodology.

3.2 COMPUTER INDUSTRY - For purging, as in most issues of importance to computer supported data processing, there is a history of attempts to define and resolve the problem. This is discussed in relation to its applicability to Army tactical data systems.

3.3 DECISION MODELS - This is a discussion of the current role of computer supported information systems and the related decision processes in the Army tactical environment.

3.4 COMPUTER SUPPORTED INFORMATION SYSTEM - This section defines the roles of manual and computer supported data processing for information systems in the Army tactical operations environment.

3.5 DECISIONMAKING RELEVANCE AND THE DATA BASE - This is a survey of the techniques employed to relate user satisfaction to data base relevance in the design, operation and evaluation of decision supporting data bases.

3.6 THE TOS DATA PROCESSING REQUIREMENTS - A CRITIQUE - This section of the report contains a description of the TOS system data processing requirements and a statement of the need for an analysis to achieve balance and proper apportionment of the total tactical operations data processing workload.

3.7 PURGING AND THE ARMY TACTICAL OPERATIONS SYSTEM (TOS) - stringent controls over the TOS applications
- initial screening methodologies
- formatted message structures
- standard terms and languages
- offline preprocessing
- use of hierarchial computer memory systems
- migration of data to lower level storage devices
- perculation of data back to higher levels of inaccessibility
- automatic suspense systems for purging
- considerations of backup or supporting systems

3.1 BACKGROUND

The authors of this analysis conducted a number of informal visits to command and control and management centers where data processing functions appeared to be somewhat analogous to those of TOS. Thus, the discussion draws upon knowledge of operations in the following centers even though not all were visited as part of the effort:

White House Situation Room
National Military Command Center
Alternate National Military Command Center
National Emergency Airborne Command Post
National Military Intelligence Center
Department of Army Operations Center
CINCLANT Operations Center
Strategic Air Command Operations Center
Southern Railways Operations Center
TOS Research Activities at Fort Hood
U.S. Army Combined Arms Combat Development Agency (CACDA)
Project Manager's Office, Army Tactical Data Systems
Army Computer Systems Command
Marine Corps Tactical Systems Support Agency (MCTSSA)
New York Police Department
American Telephone and Telegraphic Long Lines Restoration Control Center and Network Operations Center
Navy Advanced Command and Control Architectural Testbed
Headquarters, III Corps and Fort Hood
Swedish National Military Command Center
Headquarters, 2d Armored Division

Headquarters, 1st Cavalry Division
Federal Republic of Germany National
Military Command Center

Selected interviews were conducted with individuals engaged in recent command and control research, with command and control system users, and with information technology and computer data base specialists. The information gathered from these sources, from the comprehensive literature search and from the experience and training of the authors, provides the background for the this chapter.

In general, it can be stated that purging has had a uniformly low priority among the other problems facing developers of data systems. Since developers routinely design in initial excess capacities, they are not normally faced with an immediate purging problem in new systems. Difficulties associated with peak workloads are normally assumed away because of this excess capacity. For Army tactical systems there must exist not only excess capacities, but a priori methodologies to compensate for unexpected data processing demands or workloads at any time during the system life cycle. Taken together, the interviews and visits to these activities conducted by the authors contributed bits and pieces to a general understanding of purging problems and the methods for resolving them. Examples are the National Military Command Centers' automatic migration of files to slower storage mediums after thirty days without user access, and the New York Police Department's twenty-four-hour cycle for file retention and subsequent migration.

There has been little concern evidenced in the ADP literature, relating to commercial ADP applications, for system saturation or overload. Possible exceptions are such instances as the delays in processing during heavy trading days on the New York Stock Market and delays in the airline reservation systems. However, most commercial applications can absorb or compensate for the consequences of delays caused by system or data base saturation long enough to procure additional communications capacity, more computer central processing units or additional memory modules. Unfortunately, the military systems, particularly those used in the tactical operations environment, have severe size and weight limitations. Even if additional memory modules could be procured to meet the military applications, there would be no place to put the additional hardware in the computer system space allocation. Therefore, the Army ADP manager must make the system he has and its available capacities serve its intended purpose under all workload conditions and levels of activity.

3.2 THE COMPUTER INDUSTRY AND THE PURGING PROBLEM

A thorough literature search reveals little concern on the part of the computer industry for the information processing problems associated with possible ADP system and data base saturation. Indeed, the industry solution to this particular problem is to upgrade the existing system through acquisition of new and improved communications, central processing units, peripheral equipment, and additional memory modules. Obviously, it is not to the computer industry's advantage to show or teach users how to do more with an existing system configuration. However, evolving computer technology is providing the user with alternatives which can help reduce the scope of the problem.

New computer hardware and software systems will support multi-processing and multi-programming technology which will lead to system flexibility and immediate improvement in the system throughput. Thus, during peak levels in activity a system can process and store varying data processing workloads much more readily. Many of the modern computer systems have a form of virtual storage or memory capability which will enable the computer to swap pages from secondary storage in and out of main memory. In doing this, it will appear to the user that the main memory capacity has greatly increased in size.

Evolving data base management systems which permit file integration enable multiple users to access common files. This can eliminate much undesired redundancy and duplication of files and consequently reduce the requirement for additional memory. Associated with the sophisticated data base management systems are concepts of computer networks and distributed data bases. The application of these concepts at the Army tactical information systems level can enable Army system users to share remote data bases and will reduce much of the need to duplicate files that are available for accessing through the communications systems. Thus, all data that does not have immediate tactical value could be stored in computers at Corps level or above provided communications systems are responsive and dependable enough to support the tactical system accessing them. In such circumstances, the limited memory available at the Division level could be devoted entirely to the receipt and processing of information necessary for the day-to-day decisionmaking at that level and in the subordinate units.

There has been some consideration given to the development of new computer memory technologies of extremely high densities which require a minimum of physical space related to the computer hardware configuration. Such technologies are: magnetic bubbles, holographic techniques and cryogenic memory. These high density memory devices are not expected to become available in quantity until sometime after 1985.[1] Therefore, it can be expected that the current technology will be used until that time with some comparatively modest improvements in packing densities and access times. Because of this, physical space availability will limit the amount of storage available to a system.

Pertinent to the problem of data base saturation is the industry efforts to develop multi-level hierarchical storage systems.[2] The criteria for movement of the data is based on the cost of main memory and the need to access information with various time constraints. Associated with these systems will be automatic data migration which will move data between the levels of computer memory. Most Army systems will have at least these levels of memory:

- cache;
- primary;
- secondary;
- archival; and
- disaster backup.

Cache and primary or main memory will probably be either magnetic core or semiconductor.[3] Secondary memory is on-line to the computer system and located on magnetic disk, drum or other similar devices. Archival memory largely consists of magnetic tape. Magnetic tape seems to be reaching an improvement limit and may, therefore, be decreasing in importance as a storage device. Currently, magnetic tape probably still provides the best archival and disaster back-up technology. Ideally, archival storage should retain information indefinitely without requiring any power. It should be inexpensive, have good handling properties and be physically immune to any machine failure that might destroy its contents. The importance of disaster back-up and archival memory is so great that much effort can be expected to be devoted to these technologies over the next few years.[4] An important aspect of memory hierarchies is the relative confidence that a decisionmaker has that the information he needs will be available when required. Ideally, the hierarchy will be transparent to the user and flexible enough to be responsive under almost all circumstances.[5]

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[1] Dolotta, T.A., Bernstein, M.I., Dickson, R.S. Jr., France, N.A., Rosenblatt, B.A., Smith, D.M. and Steel, T.B. Jr. Data Processing in 1980-1985. New York: Wiley, 1976. p. 74.
[2] Martin, 1975, op. cit. pp. 449-477.
[3] Ralston, 1976, op. cit. p. 1341.
[4] Dolotta, et al., op. cit. p. 74.
[5] Martin, 1975, p. cit. p. 449.

In summary, technological innovations are, or will soon be, available that may help by providing far greater storage capacity within far less space. However, the limiting of data in a system, or the removal of data from a system, remains essentially a management and procedural problem which is not likely to be addressed by the industry on its own.

3.3 DECISION MODELS AND THE PURGING PROCESS

As indicated in the preceding section, the system user must solve the purging problem.[6] If he is to do this in a rational manner, he must have an understanding not only of the capabilities and limitations of the supporting computer, but also an understanding of the decision process and the part that the computer system plays in this process.

It seems safe to assume that decisionmakers working in an environment in which lives of many people and National Goals hang in the balance, desire perfect information upon which to base decisions. In this imperfect world, most decisionmakers are aware that they will almost always fall short of this ideal. Therefore, decisionmakers are willing to settle for something less. This poses the question, "How much information is the minimum essential for making a decision?" A schematic portraying typical information sources can help provide the dimensions of the problem.

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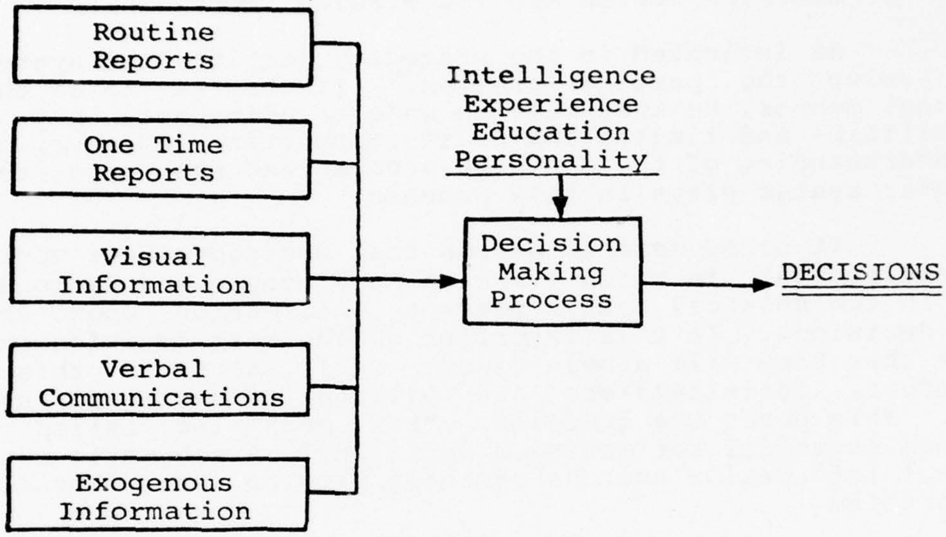
[6] Lyon, John K., The Database Administrator. New York: John Wiley & Sons, 1976. p. 119.



Information Sources for a Decision Process[7]

The total amount of information that a commander or decisionmaker will receive on a particular problem will come from a combination of these sources. In general, the computer supported system will provide routine and one-time reports. However, new and developing technology may provide some limited visual and verbal communications. Examples of routine reports are those providing general status of resources inclduing preselected measures of effectiveness. Ad hoc reports are specific responses to queries by an analyst or the decisionmaker, those exception reports provided by subordinates on their own initiative and, perhaps, exception reports programmed into the computer for release when certain conditions are met, for example, when a combat unit is reduced below 75% authorized strength in personnel or major items of equipment. Visual information can be obtained from such activities as aircraft or helicopter reconnaissance, by queries to operating units in the field and by personal inspections of problem situations. Verbal communications can include both formal briefings and casual conversations with persons possessing information relevant to the problem at hand. Information

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[7] Alexander, M.J., Information Systems Analysis - Theory and Applications. Science Research Associates, Inc., 1974. p. 79.

obtained from outside an organization can be classified as exogenous. Such sources might include magazines, newspapers, television and motion pictures.

An important point to make is that each of these information sources plays a different part of varying importance in the decision process. Individual proclivities may cause one source to be favored over another. Thus, one manager may want a great number of preformatted routine reports and another decisionmaker may stress formal briefings. Therefore, the information system must be designed in a sufficiently flexible manner so that it will satisfy the individual information demands of the decisionmakers. Once a manager has reconciled himself to the fact that all the information he requires on a subject is not available from the most favored source, he may cease his information search. If he continues, he will be forced to tap other sources of information. The ideal information system will strike a balance among the various sources be based upon not only the quality of the information provided but the relative cost of providing it. In order to reduce the possibility of information system saturation or overload, a computer application should involve only those functions it does better than manual systems, and in most cases should not be considered as the sole source of information.

Thus, a decisionmaker has a variety of sources of information. Each of these has inherent advantages and disadvantages. A computer driven routine and ad hoc reports are two of these sources of information which can be supplemented by accessing other supplementary information sources. Therefore, an information system should be so designed that it does not place complete dependence upon the compluter alone.

3.4 COMPUTER SUPPORTED INFORMATION SYSTEM

The role that the computer will play in the decisionmaker's information system is central to the design of a system for a tactical environment. Such a role is shaped primarily by the strengths which automated systems possess. Comparative strengths and weaknesses of automated and manual systems are indicated on the following table:[8]

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[8] Davis, Gordon B., Computer Data Processing New York: McGraw-Hill, 1969. pp. 1-17.

Computer Versus Data Processing

Characteristics of Data Processing	Manual Processing	Computer Processing
Speed of Execution	Relatively Slow	Extremely Fast
Ability to continue processing over an extended period	Poor	Very Good
Ability to remember or retrieve information	Relatively Inaccurate	Accurate
Accuracy of Work	Make Errors	Virtually No Errors
Ability to consistently follow instructions	Imperfect	Perfect
Ability to innovate in new situation	Fairly Good	Lacking
Ability to learn by trial and error	Fairly Good	Lacking

Man-supported systems have a distinctive advantage in numerous situations because they have a capability for heuristic reasoning and the ability to innovate and adapt. Computer-supported system can break down when faced with unforseen information requirements. The appeal of manual data processing is obvious in tactical command centers given the uncertainty and change inherent in tactical combat operations.

For most tactical systems, it will be necessary at the time of concept formulation to define what data processing applications will go on the computer and which ones will be performed manually. In general, such a decision should be made based on the advantages that the computer has over the manual processing methods. Even after such a decision is reached, it will be necessary to screen data before processing on the computer. Available computer memory will almost inevitably be less than desired. Despite this, no amount of careful system design can completely preclude the chance that system saturation will occur.

3.5 METHODS CURRENTLY USED TO ENSURE THE DECISIONMAKING RELEVANCE OF A DATABASE

A variety of techniques are currently employed which attempt to incorporate user satisfaction with data base relevance into the design, operation and evaluation of decision support data bases. This section will survey such methods. Techniques will be described that are useful for: determining informational requirements for the decisionmaker; managing the data in a manner conducive to efficient retrieval of relevant data; and/or evaluating the decisionmaking utility of the data base. Three specific document-processing and decision-aiding systems which incorporate these various techniques are decribed below.

3.5.1 DAISY System

This system, as described by Hurst, et al.[9] employs a variety of techniques which relate to these goals. DAISY is an information modeling system designed to assist decisionmakers with complex, interconnected sequences of decisions. One technique employed in the system provides a gatekeeper for the decisionmaker who wishes to be kept informed on a variety of prespecified topics. Such an automatic notification system is built by a "dynamic check list" of topic areas which the decisionmaker is able to modify with changing decisional requirements.

The system also provides for personalized retrieval with its context saving and restoring feature, with which the user can save, load or delete specific components of a decision's context for future use. It is also adaptive to the user in that its file system permits the location and search strategies employed by the system to change as need for different parts of the data base change. It will move data about a specific area of interest into the fastest access position.

Perhaps the most important aspect of the DAISY system -- in terms of purging considerations -- is its use in running simulations with multiple decisionmakers. Across these users, common informational requirements for specific decision situations are analyzed. The author notes that "in areas such as military tactical planning, where individuals frequently change positions or assume new positions, such a system could build up knowledge over time by noting the specific decision alternatives most likely to be chosen, and the information which has been most used in the decisionmakers.

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[9] Hurst, E.G., et al., Daisy: A Decision-Aiding Information System. University of Pennsylvania, Wharton School, Paper No. 75-01-05, 1975.

3.5.2 RADCOL System

Describing the RADCOL System, Morris et al.[10] suggest that users should be provided with a relevance feedback channel in which to make open-ended reactions to the system performance. A monitor log would also be useful to identify over- and under-utilized system features. Also recommended are retrieval techniques that allow the user to save earlier queries for combination with, or revision of, later queries. "Rapid scan" and "expanding" options are also promoted. With "rapid scan" the user can examine a brief summry of ech document retrieved and "expand" it (i.e., see entire document) if he so chooses.

The RADCOL System, somewhat based on Salton's work with the SMART System, provides document-document searches which let the user retrieve documents on the basis of their similarity to other documents in the data base. Thereby, if the user can locate one relevant document, his chances for locating others are increased.

RADCOL employs a relevance feedback mechanism. Users execute query A and provide relevance judgments for documents thereby retrieved. The next query is then automatically formulated for greater congruence with items identified as relevant and less congruence with nonrelevant items. The procedure is accomplished by the assignment of weight increases for terms associated with documents judged relevant and weight decreases for terms associated with nonrelevant items.

The authors discuss standard methods for evaluating the effectiveness of retrieval systems. Recall is the ratio of number of retrievals judged relevant to the total number of relevant documents in the data base. Precision involves the ratio of the number of relevant retrievals to the total number of retrievals. Where the figures necessary to compute these ratios are unavailable, the data base relevance measured would simply record whether a given query produced a relevant message and/or how many messages were retrieved before a highly relevant message was obtained.

Where retrieval systems like RADCOL are based on statistical measures of message similarity to query (e.g., stem-stem correlation), one can compare human and statistical estimates of relevance. Judges are given pairs of documents from the data base and asked to estimate the degree of similarity between them. System correlation assignments are compared with human correlation assignments in terms of rank order assignment.

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[10] Morris, J.M., et al., RADC: On-Line Retrieval System Evaluation. Pattern Analysis and Recognition Corporation, Report No. RADC-TR-75-208, 1975.

It should be noted that RADCOL gives the user complete information about the underlying logic of a search: a list of query words; document concept vectors; an ordered list of documents retrieved; and correlations between the query and retrieved documents. In an operational setting, the user has all this information to modify his query toward greater precision.

3.5.3 SMART System

Salton[11] describes a dynamic document processing system in which clustered files are searched and information is retrieved through an interactive user-controlled search process. In the SMART System, a vector matching function is computed for all query-document pairs and a coefficient of similarity is obtained with which output documents can be rank ordered in terms of degrees of similarity with the query.

The system uses a clustered file organization in which documents carrying similar content descriptions are automatically grouped into clusters. Clusters are identified by profiles, a set of weighted terms representative of the clustered documents. A search in the clustered file is executed by comparing each query with the file of profile vectors. For those profiles with sufficient similarity to the query, individual document vectors in corresponding clusters are examined and documents are ranked for output in decreasing query-document similarity.

SMART uses a relevance feedback query alteration technique in which queries are automatically updated using relevance information furnished by the user about previously retrieved documents. After an initial search, a small amount of output is presented to the user who distinguishes relevant and nonrelevant documents. The next query is altered to increase the weight of relevant documents and decrease the weight of nonrelevant documents. Salton states that relevance feedback produces the best results of all the interactive retrieval methods, while placing the least burden on the user; yielding improvements up to 45% in recall and precision.

Furthermore, SMART uses customer intelligence to improve the document vectors by promoting documents judged relevant and demoting others. That is, it renders documents judged relevant more easily retrievable by making them more similar to the query used to retrieve them and documents judged nonrelevant are shifted away from the query. After a large number of queries, documents wanted by users are gradually moved into the active portions of the document space and documents rejected

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[11] Salton, G. Dynamic Document Processing. Cornell University, Report No. CSD-CU-72-121, 1972.

are moved to the periphery and eventually may be discarded. The procedure alters the document vector for items judged relevant by adding query terms or incrementing the weights of terms jointly present in the document and query vector. These same document vectors are also modified by assigning lower weights to document terms absent from the query. Conversely, for documents judged nonrelevant, document terms jointly included in the document and query vectors are reduced in weight and terms absent from the query are increased in weight.

The same strategy is used for profile alteration. Whenever a relevant document vector is changed by adding terms from a query, these same terms are used to update the corresponding document profile. The weight of profile terms also present in the query's is increased and terms not already present in the profile are added to the profile vector. In addition, the SMART System develops user query clusters in a manner similar to document clustering.

Finally, Salton considers the problem of document retirement (i.e., removal from the central file system which is searched with each query to an auxilliary storage area specially accessed). He proposed a retirement policy suited to the dynamic document environment. Specifically, he recommends a "generalized document vector modification policy" based on: the closeness of a document to the set of query profiles; the rank of a document in a list of retrieved items; and user judgments of nonrelevance. The consequence of such a policy is to shift documents that are close to query profiles or are retrieved with a low query output rank or are known to be relevant to the users' needs closer to those queries where user interest is concentrated. Conversely, documents having opposite relevance weights are shifted away from current query positions. The long-term consequence is that items never wanted or items low on the retrieved list are eventually made irretrievable.

Two major conclusions can be drawn from this overview. First, there is evidence of increasing concern for the incorporation of user satisfaction data in the design, operation and management of decision-support information systems. Secondly, questions of efficient data base management and of comprehensive system evaluation methods are initially and ultimately questions of determining the information needs of a decisionmaker. Effective retrieval and evaluation techniques necessarily flow from the determination of these needs, and progress in validly determining information needs is probably the most critical research requirement in the overall task of developing a successful purging system. For these reasons, the final section of the chapter will deal exclusively with the range of methods available for valid determination of decisionmaker's information needs.

3.6 THE TOS DATA PROCESSING REQUIREMENTS - A CRITIQUE

A prime concern leading to the decision to undertake the preparation of a report is the concern for the possibility that the data processing requirements of the Army TOS system might at times of high levels of combat operations, "...soon swamp the memory and disk/tape capacity of the computer system -- a case of storage overload."[12] A review of the TOS descriptions in various Army documents reveals that this storage overload is a distinct possibility for even moderate levels of crisis or combat operations.

The requirements of the system users are decribed in general terms below:[13]

- Intelligence

  - planning and coordination of reconnaissance and surveillance activities;
  - intelligence mission management and dissemination;
  - coordination of all intelligence activities;
  - enemy situation (ENSIT) file management;
  - intelligence analysis and production;

- Operations

  - friendly situation (FRENSIT) file management;
  - monitor combat operations;
  - develop and coordinate detailed tactical planning;
  - consolidate, coordinate and approve all preplanned tactical air strike requests;
  - develop operations plans and orders;
  - transmit graphic displays of proposed courses of action;
  - transmit approved plans to subordinate units for implementation;

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[12] U.S. Army Research Institute for the Behavioral and Social Sicences, Appendix "A" to contract DAHC19-76-C-0050, Statement of Work, p. 1.
[13] This description of the TOS requirements was taken from a draft Army document. The source of this document indicated that, although this was not an approved statement of requirements, it did accurately state the then-current thinking of what the TOS applications should be.

- Fire Support Element
  - coordinate data requirements between TOS and TACFIRE;

- Administrative/Logistics
  - personnel;
  - administrative;
  - logistics information;

- General
  - support operations/intelligence planning analysis; and
  - provide information of an immediate nature to the Division tactical operations center and the tactical command post as required.

In the administrative/logistics area this information will be in the form of extracts from the data bases maintained on combat service support computers and not the entire files. These requirements appear to place a large share of the total data processing workload on the computer and the users do not take into consideration the need to strike a balance among the various information sources available to a decisionmaker.

The determination of the actual scope or magnitude of the computer's role will be based on the capability and limitations of computers supporting data processing in the tactical environment, their associated communications and the ability of other information sources to augment this capability to satisfy the total information requirements. The selection of the specific role of the computer, the application programs, and the various files to be stored in computer memory is beyond the scope of this study. However, once the system configuration has been selected and the file structure defined, there are a number of methods, tools and techniques which can be used to prevent storage and system overload. These will be discussed in subsequent sections of this chapter.

3.7 PURGING AND THE ARMY TACTICAL OPERATIONS SYSTEM (TOS)

The detailed discussion of purging technology is contained in Appendix A. However, they will be discussed briefly also in this section in order to provide a view of their relationship to the decisionmaking process.

A review of the various TOS documents indicates an apparent philosophy that it is desirable to automate as much of the operations and intelligence data processing for the Division as possible. Inevitably, this will set the stage for information, system and storage overloads. A more reasonable approach would be to require strong justification for any data processing application to be supported by the automated TOS system. The burden of proof should be the responsibility of those who would add a new TOS system application or enlarge an existing application.

For the purpose of the review of the computer associated methods, tools and techniques for purging, it will be assumed that these hard decisions on applications have been made and that the functions performed by the computer are those that justify automated processing.

If the broad view of purging is taken, it will involve any process which will help prevent system and storage overload. This is contrasted to the narrow view which would restrict the consideration to removing selected data elements or files from the hierarchy of computer storage devices. Any comprehensive program designed to prevent system and data storage saturation will begin with the screening of data prior to its introduction to the computer system.

In almost every command center organization there is a message center that receives the various types of reports and messages from subordinate, adjacent and higher level units. Each document will process through some initial review or screening which may be very broad gauge. For example, the person screening messages may look for addresses, precedence, sending organization, type of message (action or information) and redundancy. In most cases, the initial check for redundancy will be for exact duplication of information already received because it often takes a subject area specialist to determine if similar messages actually carry no new information. This screening process is the first level of purging. It is possible at this point to make major reductions in the amount of computer data storage required.

The next level of screening will normally be carried out in the areas of the functional specialists in tactical combat operations. It is here that much of the redundancy of information will be identified and filtered out. The result will be that many of the incoming messages will be destroyed without further processing. In addition, information on the messages considered relevant may be categorized according to the volitility or useful life of the information. For example, in the manual message processing relating to tactical operations, messages may be placed next to the operations map with the information keyed to a specific location on the map. When this information is considered to have lost its relevance, the mark on the map and supporting message will both be destroyed.

As indicated previously, data is captured in a variety of forms for Army tactical systems. It can be in the form of hardcopy messages, signals in the form of telemetry from various sensor devices, telephonic or radio reports to command centers and computer readable information from other automated systems such as decks of punched cards, copies of magnetic tapes, signals from other systems on a computer network and, in the future, voice or handwritten documents. If the amount of data in storage is to be reduced or used to best advantage, there must be a variety of efforts applied to eliminate unnecessary, redundant and erroneous data at the time of capture and throughout the processing cycle. There are various manual, semi-automated and automated checks which can eliminate much of the data which has limited or no potential utility and could fill scarce storage space on the system. These include reasonableness and redundancy checks. In addition, there are a number of techniques available such as those which will eliminate non-variable data and provide for the entry of only variable data (see discussion in Appendix A). The application of standard language and standard formats for reporting data will serve this purpose.

Another approach to saving space on tactical computer systems is through the use of a standard limited vocabulary command and control language. To date, there has been some success in standardizing terms within the Department of Defense and the NATO community. If such a command and control language could be developed and limited to something less than 1,000 words, each word could be coded and stored using less than 16 bits per word. Normally it takes eight bits to code one alpha-numeric character. In discussing the possibility of developing a standard command and control language with various persons experienced in Army command and control and with personnel from the New York Police Department, it appears that users feel that this would be too restrictive and would take too much from the information content of messages. However, it is an approach that is worth additional study.

As was indicated earlier, one of the major purging procedures for manual systems is the initial screening. Almost every command center visited has procedures for screening messages. This is a particularly effective purging method because, even an untrained clerical person can spot message duplications, messages that are so garbled as to be unreadable and messages that are misrouted. In addition, the trained tactical opeations staff analyst normally performs the finer screening which will provide better message distribution, identify messages that have no utility and determine the time utility of certain messages. However, for messages being entered in automated systems, it is generally believed that this detailed manual screening may slow message processing an unacceptable amount.

In the tactical operations environment, manual screening of hardcopy messages and messages which appear on a terminal screen may have advantages that far outweigh any delay generated by manual review. Some of these advantages are:

- the volume of messages stored may be reduced by as much as twenty percent;

- the reviewer may be able to correct the distribution instructions;

- it is possible that a hierarchial storage sequence can be assigned which will support the automatic migration of messages out of the computer main memory and subsequent purging, based on an assigned suspense time or date;

- the reviewer can extract from the message only those items that have future utility and just store that portion; and

- the reviewer can request a hardcopy printout and decline to have the message stored in computer memory.

Advantages which will accrue through manual review by headquarters staff members of messages in an automated system are so compelling as to justify serious consideration of the feasibility of establishing such a system. This is particularly important when there is danger of system saturation.

The TOS system is characterized by a Central Computer Center (CCC) which is supporting and being supported by a variety of peripheral systems such as the Remote Computer Centers (RCC), the Message Input/Output Devices (MIOD) and the Digital Message Devices. Augmenting the TOS system are the new and developing means for improved surveillance and target acquisition and the related sensor technology. A major factor in the developing concern for system, information and data storage overloads is the scenario in which all of these devices are turned on to peak levels of activity at once. Such a condition might well exist during a crisis situation and during active combat operations. One can imagine a flood of data traffic between data processing stations and their users and demand for data processing support that would far exceed that generated by individual system tests. However, early planning will enable the system to absorb much of this increased workload.

In consideration of the Remote Computer Centers, the Message Input/Output Devices and the sensor systems, there is a potential to do much of the processing normally expected of the Central Computer Center off-line. For example, much of the telemetry from the sensor systems can be converted from analog to digital data and summarized off-line prior to transmission to the

Central Computer System. In the case of the Remote Computer Systems and the Message Input/Output devices, much of the data to be transmitted to the CCC can be pre-processed to the extent that the majority of the raw data is eliminated and only relevant intelligence and operatios information is transmitted.

The designers of the TOS system should recognize the dangers involved in possible system and storage saturation and plan, in the concept stage, for the capability to pre-process data as much as possible prior to its transmission to the central system. The technology associated with microprocessing and intelligent terminals will support this effort to reduce the peak level demands on the central computer system through pre-processing of data.

Once the data has been entered into computer memory, there are a number of actions that can be taken to prevent memory system overload. These are, in the main, the normal data base management functions conducted in most command and control centers which take on an increased level of importance for Army tactical systems. In order to put the data base management functions in perspective it is necessary to reexamine the common hierarchy of computer memory indicated earlier, that is:

- cache;
- primary;
- secondary;
- archival; and
- disaster back-up.

The cache and primary memory are the extremely fast rapid access-storage elements from which instructions are executed and data operated on. The secondary memory is normally of large capacity which is on-line to the main memory (cache and primary). The secondary memory has longer access time and permits the transferring of blocks of data between it and main storage. Archival nd disaster back-up storage are associated with off-line storage devices which include magnetic tape systems and such technology as microfilm computer output (COM).

Data base management includes those methodologies and procedures necessary to allocate to each memory device only the data required for the responsive functioning of the system. For example, daily operational data for the TOS system will most likely reside either in main or secondary memory. Intelligence data, which is probably of much greater volume, will be divided among main, secondary and archival memories. Part of the data management function is the migration of data from the limited fast memories to the slower, high volume storage units. In addition, provisions must be made to perculate this data back to the more accessible memories. Of prime importance in data base management is the determination of when to move data in the hierarchy and when to purge data from the storage system completely.

The command center visits revealed a number of procedures which are currently in use to define how data in data bases should be managed. For example, some of the data bases supporting the National Military Command Center are automatically reviewed for purging if they have not been accessed or used for thirty days. Other systems, such as the New York Police Department system, migrate data down the storage hierarchy or data base according to a predetermined criterion. In each case, there must be a well considered determination as to what the expected utility of specific files or categories of data will be. Of course, this determination will be subject to major adjustments and the system must be designed flexibly enough to adapt to the required changes. In the case of tactical operations, if the involved units advance beyond a geographical area, the related information may no longer have any value. In static combat conditions, the intelligence data value may have great utility over an extended period.

In the interviews associated with this research it was determined that decisionmakers will not support completely automated data migration and purging procedures. In almost every case, there was an expressed desire to go over listings of data manually in order to determine present and future utility. This review process coupled with an automated suspense system appears to be the most acceptable methodology. For example, the computer can be programmed to print a listing of those files which have not been accessed for 120 hours. The user could indicate which files should be retained in the current storage medium, which can be migrated to lower levels, which should be placed in archival or disaster back-up and, finally, which files should be permanently purged from the system. Of concern for this approach is the availability of users to perform the necessary detailed analysis of the files during crisis or combat operations.

A prime consideration in making purging decisions is the availability of back-up or supporting systems. For example, if there are computer systems at the Corps or Army level, which can serve as a data base resource for the TOS system, the TOS system users can be expected to be more willing to purge their own system. However, this back-up must be dependable both from the aspect of communications support and that of available data processing capacities. At the same time, it can be expected that future tactical systems will be designed in such a manner that the systems, such as the TOS, will feed the larger systems at Corps, Army and Theater levels. As these systems gain in their dependability and data base sophistication, more and more of the TOS data processing workload may be shifted to these systems. In addition, these larger systems will not be constrained by physical size, power and communications limitations as the current tactical systems are.

Chapter 4

COMBAT INFORMATION REQUIREMENTS AND PURGING PROCEDURE ALTERNATIVES

Development of suitable techniques for the removal or the elimination of excessive data from the Division TOS is dependent upon the identification of the particular data that ideally is required for specific functional performance within the TOC, and the delineation in general terms of the time windows within which this information must be available for optimal effect. Accepted U.S. doctrine for the conduct of land combat is examined analytically in Section 4.1 to fix the decision parameters at Division level. This forms a basis for subsequent development in Section 4.2 of criteria for information deemed essential for mission performance and for effective command and control of organic elements by the Division commander and his staff. Criteria for distinguishing data that can be completely purged from that which can be moved to a slower storage medium is then analyzed in Section 4.3. Section 4.4 concludes the chapter with a discussion of possible rules, techniques and operations that might be employed to purge information from an operational TOS.

4.1 LAND COMBAT AT THE DIVISION LEVEL

The ultimate objective of warfare is to impose one's will physically upon an opponent. Military success or victory -- gauged by attainment of specified goals or the frustration of an opponent's aims -- results from the concentration of superior force at critical points or in critical areas. In modern land combat, physical engagement of forces occurs at battalion level and below. Thus, while battalion and brigade commanders direct and control the immediate conflict, their subordinates, the captains with their companies, troops and batteries actually fight the battle. At Division level, the commander and his staff issue the directives and orders that are needed to concentrate the forces, allocate the resources and establish the priorities within which conflict is joined.[1]

Given the comparatively large military establishments possessed by most modern industrial states, Division sized elements rarely operate alone or in isolation when engaged in conflict. Thus, combat missions assigned a ground Division normally fit within the context of a larger scheme of operations involving a Corps or Army Group, or within the operative frame of reference for a Joint Task Force conducting a highly specialized, limited operation. In such frameworks the Division commander is told "what to do", operational constraints may be imposed in terms of "rules of engagement", but the "how" of mission accomplishment

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[1] U.S. Army Field Manual No. 100-5, Operations Washington: Department of Army, pp. 3-5 to 3-14. 1970.

within accepted doctrine is usually left to the Division commander and his staff. Assuming that resources organic to and in support of the Division are adequate to the assigned task, the commander organizes his forces, plans a scheme of maneuver, allocates priorities for supporting fires and issues specific instructions to major subordinate commanders. Such instructions take the form of assigned missions, assigned operational areas and the allocation of combat support. Thereafter, the Division commander's concerns are principally with the progress of the battle and with action required to sustain his own forces -- resupply, repair and the replacement of personnel and material.[2] The information that he and his staff are most interested in during the course of the battle is that which enables this group to take necessary action to insure that the conduct of the battle proceeds collectively as much as possible as planned, adjusting organizational structure, maneuver and priorities of fire as required.

At first glance, the complex nature of ground combat conveys an impression that actual informational needs for command and control at Division level are infinite. A large number of friendly units are or can be involved. Most of these are organic to the Division itself, but others may be supporting or temporarily attached to the Division. These elements vary in authorized size and strength, and actual numbers can fluctuate on a daily or even hourly basis. The geographic area over which combat is joined, is comparatively large (1500 square kilometers or more) and may be diverse in nature. Extensive coordination of all combat elements and of supporting weapons systems is essential for maximum effective generation of combat power. Some uncertainty always exists as to opponents' intentions, strength and unit locations and enemy activity can and does have a variety of purposes and meanings.[3] All this action frequently occurs in an area subject to vagaries of changing weather. Ideally, the Division commander would like to have timely, accurate information relating to all of these factors in sufficient detail to insure that he and his staff make the soundest selections among alternative courses of action. In point of fact, current information such as intelligence summaries, operation or situation reports, received at Division headquarters in typed or printed document form very seldom influence <u>immediate</u> operational decisions, although such information can be extremely helpful in monitoring overall combat activity and for future planning. After the Division is in motion, the commander delegates responsibility for detailed monitoring of events and for coordination to his staff and other agencies in accordance with accepted doctrine for command and control and for force employment. The staff and these coordinating agencies act as filters that screen most of the data flow and convey only <u>vital</u> information to the commander.

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[2] FM 100-5, op cit.
[3] FM 100-5, pp. 7-1 to 7-17.

They employ the more detailed information to support their own functional responsibilities.[4] Such activities can involve the direction of supporting weapons systems, or measuring trends, monitoring progress and aggregating totals to identify critical thresholds in status or activity associated with such specified areas as personnel operations, logistics, intelligence, etc.

For analytical purposes in determining essential informational needs, combat at Division level can be viewed as two rather distinct but related activities. First, that portion of the battle involving forces that are in direct line of sight of each other. Normally, this segment of the battle occurs at a range from 1 to 3 kilometers (can extend to 5 kilometers) and concerns the direction of fire against enemy targets that can be seen or against observable locations were it is suspected enemy elements are concealed. This segment of the division battle involves the employment of both flat trajectory and indirect fire weapons. The artillery, which is provided principally by units organic to the division, is primarily controlled by forward observers with the engaged companies and battalions. This high trajectory fire, which can be quickly and effectively massed, substantially increases that combat power which can be generated in the immediate battle area. The line of sight battle is directed and managed by brigade and battalion commanders with resources previously allocated to them. Details of the conduct of this battle below the level of battalion aggregate are not normally of interest at Division headquarters.[5] Rather, the Division commander's concern is primarily with the conduct of the battle in accordance with previously issued instructions, and with the maneuver of reserve or of additional forces into a given area of action to increase troop and weapons density thus strengthening combat power so as to attrit or destroy increased number of opponent forces and more enemy material. Maneuver as it relates to the line of sight battle involves the movement or relocation of forces so as to enhance the effectiveness of direct fire weapons, or exploit the success of friendly elements, or to restore a balance where opponents actions have, in fact, tipped the ratio of combat power against friendly forces.

The second portion of the divisional battle actually involves those aspects of conflict that occur beyond line of sight -- behind that 3-5 kilometer zone where troops are face to face. Here focus is upon attacking and destroying supporting weapons, command and control installations, support facilities and those reserve enemy forces capable of moving forward into the line of sight battle. This portion of the conflict involves delivery of ordnance by indirect fire weapons with greater range or by missiles and aircraft. Responsibility for the actual

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[4] U.S. Army Field Manual No. 101-5, Staff Procedures Washington: Department of Army and FM 100-5, pp. 12-1 to 12-13.
[5] FM 100-5, pp. 3-5 to 3-8.

employment of weapons, the direction of fire, the direction of orbiting aircraft, and the techniques of massing firepower are left specifically to designated subordinate or coordinating agencies.[6] For example, the Division artillery commander is responsible for actual coordination and execution of indirect fire missions. An elaborate mechanism exists for gathering data and issuing fire instructions to guns to attack targets of opportunity quickly in the Division area. Neither the Division commander nor his immediate staff are personally involved in the target location/target engagement loop except in the role of ultimate arbiter so far as priorities of fire are concerned, or as directing authority for the use or release of nuclear weapons, or in quick response reaction against possible enemy nuclear delivery systems. However, the Division commander is vitally concerned with the location and movement of enemy units of battalion size or larger and of nuclear delivery systems that can be brought to bear on the line of sight battle, or against any friendly elements in the division area.[7]

For both portions of the battle, the Division commander and his immediate staff are concerned primarily with essential shifts of priorities, with emergency changes in mission assignments, with commitment of reserves, with requests for additional resources from higher headquarters and with supervision of support functions. This has been long recognized and divisional staff elements operate within well-defined functional areas. In these areas, selected data is gathered and activities and developments monitored continuously. To this end, Army Divisions establish intricate, formal standard operating procedures (SOP's) that prescribe the operational and intelligence reports necessary for the supervision and coordination of all Division activities. In general, these tend to be quite similar for all Divisions. An example of the scope, frequency and type of required reports is contained in Appendix B, an annex prescribing reports taken from a typical division tactical SOP. Little of the information furnished in these reports is employed for immediate operational decision in the Division (except as background or supporting information), however, much of it can be employed to secure personnel and material replacements and in future planning. The information which can be used that will influence action in progress, such as that indicating development of a major enemy penetration, normally has a comparatively short useful life, and must be immediately brought to the attention of the appropriate agency or staff principal and to the commander in order to attain a suitable response within the effective time window during which remedial action is possible. This particular information must be presented or available for presentation to the Division commander in real or near real time, preferably in symbolic or pictorial form and matched to terrain maps. Criteria discussed below seek

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[6] FM-100-5, pp. 2-12 to 2-17.
[7] FM 100-5, p. 10-5.

to identify in more specific terms what information is actually essential for immediate operational decisions at Division level.

4.2 CRITERIA FOR DISTINGUISHING ESSENTIAL DATA

In the employment of a Division sized military force, the Division commander and the staff who assist him in preparing and issuing instructions that set the force in motion and make adjustments for changing conditions do so with some understanding of the situation confronting the Division. In essence, this mental picture of the situation and the orders issued to cause the physical interaction of opposing forces serve in the real world as a predictive model for events as the commander envisions them and intends them to unfold. The command and control mechanism of the Division headquarters and of subordinate elements provide the conduit for data or information feedback from the operating elements. This feedback describes real conditions and events (actual observables) required for comparison with, and adjustments of those plans and instructions (predicted observables) comprising the original decision model. The information flowing through this feedback mechanism can either increase or reduce the uncertainty confronting the commander and his staff, although the latter is more normally the case. In any event, the information itself, that in the predictive model as well as that returned through the feedback mechanism, has some accepted value. When this aggregate value exceeds an identified or established threshold, the information can be considered essential for a given decision situation.

The scope of remedial action which the Division commander and his staff normally can take to influence actual observables deviating from the predictive model largely sets thresholds that distinguish essential data. Although the Division commander himself is theoretically responsible for everything that occurs within his area of operations, much of the detailed battle management is delegated to subordinate elements; leaving him and his immediate staff responsible principally for the movement and coodination of major maneuver elements, adjustments in fire priorities for supporting weapons systems, employment of those very few weapons delivery systems retained directly under division control, and planning and preparing for future action. Information needed to perform these functions must be of the same level of detail as that with which the commander deals in organizing his own forces, i.e., for enemy forces at the level of division, regiment, and battalion plus information on such special lower echelon elements as nuclear delivery systems, bridging, electronic warfare activities and air defense.

Information utilized for battle management falls essentially into three distinct categories:

- that relating to the environment, the weather, the nature of the terrain over which the battle is or will be joined, etc.;
- that relating to friendly forces status and disposition; and
- that relating to enemy capability, intentions and deployment.

So far as the first of these three categories is concerned, much of the information required at Division level is normally available prior to actual force engagement. This is presently obtained principally from maps, aerial photographs, weather projections, historical records, ground or aerial reconnaissance and the like; although at some future date such may also be provided to a field headquarters in digital format directly via satellite from continental United States. Such information will largely be in pictorial or graphical (map) format and will not change substantially during an operation except for weather and limited adjustments of man-made objects such as destroyed bridges, etc. Since this information is used continuously to follow operations as the battle progresses across a given extent of terrain, it appears unlikely that any great quantity of this information will be placed in the automated TOS at Division headquarters, at least during the foreseeable future. The other two categories of information, however, are appreciably different since the status, disposition and employment both of enemy forces and of friendly forces are constantly changing, and since such information in aggregate form is utilized to make adjustments during the progress of the battle, and to plan future action.

All activity as well as the detection of physical presence occur on the battlefield in some temporal sequence, and each can be related at a given time to either a general or specific location. Such information usually contains all or part of the five following elements:

- Who or what agency or activity was involved?
- What actually happened, or what is the status being reported?
- When did the event occur, or when was the status determined?
- Where did the event take place, or where is the organization making the report located?
- How did the event transpire, and what were the special circumstances associated with it?

To this can be added the reporting agency if such was not contained in the above five at the time that the report was actually formulated and forwarded. Thus, content analysis permits formatting of these messages and substantive abbreviation that lends itself particularly well to the computerization of reports forwarded in either textual or digital format, and sould facilitate information aggregation.

Essential data for the direction of combat at Division headquarters level must be sufficiently timely to enable the commander and his staff to issue those necessary orders to set and keep the Division in motion. As pointed out above, this involves planning for the action, and the initial and subsequent issuance of instructions as a result of the monitoring of both enemy activity and the status of friendly forces aggregated at battalion and brigade level. While information relative to the status of friendly forces is either continuously available or can be obtained from the units concerned within a given timeframe, information relative to the disposition and to the deployment of enemy forces will always be somewhat clouded and obscured. Even under the best of circumstances, all desired information relative to the activity and status of enemy elements will not be available to a commander if, for no other reasons than because of enemy deceptive tactics or because given sensor systems fail to perform properly, or are destroyed or otherwise rendered ineffective. As indicated in Chapter 1, there is a clear association between the amount of data available and the confidence and comfort with which a commander or his staff reach a given decision. The desired threshold of information above which a commander and his staff at Division level will function effectively can vary with individual commanders. However, balance must be struck between an inordinate amount of detail which cannot be readily synthesized and aggregated for decision and a lack of detail that produces a degree of uncertainty unacceptable for a given commander.[8] In general terms, information falls within this threshold if it is essential to a vital decision and its presence or absence will mean absolute success or failure, so far as Division missions are concerned. Hence, the following eleven specific categories appear to constitute essential information:

- Information indicating that the ratio of enemy combat power to friendly combat power in a given brigade area has become, or is about to become, so adverse as to threaten Division mission or brigade mission accomplishment.

- Information indicating a requirement for major adjustment of existing friendly dispositions and boundaries, or major changes in the existing or proposed scheme of

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[8] Dixon, N.F. On the Psychology of Military Incompetence. New York: Basic Books, pp. 27-35. 1976.

maneuver or major changes in the priorities for fire support.

- Information regarding employment or suggesting possible employment of enemy nuclear weapons and chemical or biological agents.

- Information relating to the planned employment of friendly nuclear weapons, or chemical or biological agents or relating to friendly nuclear accidents.

- Information indicating major friendly force vulnerabilities which can be corrected by Divisional agencies or for which assistance can be acquired from higher headquarters before enemy exploitation is possible.

- Information that will enable the Division commander to employ his available assets so as to attain directed goals successfully if such information reaches him in time.

- Information of enemy presence or activity, and information of friendly personnel and material status, and information regarding weather conditions or geographic features, the possession or absence of which can substantially alter the probability of successful attainment of assigned Division missions.

- Information of current or recent enemy force movements (battalion size or larger) that can be utilized by the Division staff to predict or project current or future enemy intentions. Generally this information is limited to that relating to enemy actions to which the Division must react in from two to twelve hours or plan for in the next twelve to twenty-four hours.

- Information relating to the coordination of activity between major subordinate elements of the Division and of adjacent Divisions, or between direct or indirect fire of adjacent friendly brigade sized units, or between Division elements and supporting friendly Air and Naval forces. Details regarding such fire coordination lines are essential both for artillery fire direction (accomplished by Division Artillery), and for coordination with adjacent and higher headquarters (accomplished by the Division TOC).

- Information relating to planned friendly force movements in front of the forward edge of the battle area for that period during which such force movements actually take place. Of course, such information must be furnished with sufficient lead time for the Division to affect necessary coordination with adjacent units to insure that friendly fire is not inadvertently directed against these forces during the operation. This is particularly important for the vertical movement of forces with helicopters.

- Information regarding areas which are denied to friendly force maneuver (both on the ground or via helicopter), either as a result of the location of mines, heavy weapon concentrations, anti-aircraft fire, non-traversable geographic conditions or features, or nuclear, chemical or biological contamination, etc.

Key to the effective use of such information at Division headquarters level is the grain of detail and the time response window within which the commander and his staff can and must react. Except for information relating to specific activities such as enemy nuclear delivery systems, the Division TOC is concerned primarily with enemy units of battalion size. Ideally, company sized elements will be aggregated by reporting brigades or sensing systems. It serves no useful purpose to tell the Division commander or his staff the whereabouts of a given machine gun or a given tank, or even several tanks. The engagement of individual targets by batteries or battalions of artillery obviously requires information of finer grain of detail. This detailed information will normally remain in the fire direction-fire control loops; however, results of such fire missions will be aggregated by the Division artillery fire direction center or by the manager of the weapons employment system involved and forwarded to the Division TOC periodically on a summary basis. The TOC should not be involved in actual, individual target selection since that function can only be slowed by placing another agency directly in the weapons employment loop.[9] Identification of the broad categories of information that are essential for successful Division combat operations, and careful delineation of the degree of detail required in such categories, permits the establishment of procedures for handling and processing the information which can most profitably be automated at Division headquarters for tactical decisions. This information should not be automated, however, if, in fact, automation either slows the passage of essential information to the commander, or if automation of too much of this information makes it impossible for the division commander and his staff to reacquire essential information needed for appropriate decision or to control and direct friendly operations.

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[9] Kroger, M.G., et al. "Integrated Tactical Information System Design Study (ITIS): A Study of Tactical Information System Requirements Current Capabilities and Steps Toward Future Goals," (V). Marina del Rey: R&D Associates, pp. 3-6-3-20. 1976 (SECRET).

4.3 CRITERIA FOR DISTINGUISHING DATA THAT CAN BE COMPLETELY PURGED AND DATA THAT CAN BE PURGED TO A SLOWER STORAGE MEDIUM

Ideally, information stored and processed by the TOS at Division headquarters should be that which will be immediately used by the Division commander and his staff while the battle is in progress, and that which is most likely to be of value in planning the next phase of the battle. Information relating to past action, that over 24 hours old, is of little, if any, use at the Division headquarters itself except possibly as an historical record. While such historical information may be needed at higher level (Corps or above) for pattern analysis of past events and for possible projections of future enemy intentions, such analysis requires greater human resources and more data processing than TOS presently envisions (See Appendix D -- TOS Operational/Organizational Concept). Nor should TOS be employed simply as an electronic file cabinet where all textual messages to the division Tactical Operations Center (TOC) from subordinate elements or higher headquarters are filed for future recall without regard to content perishability.

At present, the command and control mechanism within the TOC is frequently stressed during a combat situation or during crisis involvement. This strain in the TOC can grow out of a number of factors: overloaded or interrupted communications, unwieldy procedures, inordinately large amounts of information, prolonged adverse developments, personnel fatigue, a commander's idiosyncrasies, etc. Undoubtedly, part of the confusion can result from inability either to handle properly that information reaching the TOC, or to perform the necessary comparison and analysis of disparate information to quickly produce an accurate and timely portrayal of the operational situation. As an automated system for storage and retrieval of selected information, TOS holds promise of providing some help in performing these operations in the TOC at moderate cost in terms of the human and material assets involved. To be of greatest use, however, information handlng procedures must be employed with TOS that can benefit from automated support. Thus, if the problem is one merely of reading and digesting a large volume of textual messages, placement of such messages in automated storage (particularly if the inputing process is performed manually) will be only of limited benefit if this information is recalled in the same verbal format when the system is stressed by increased tempo. Key to the creation of an effective automated system is a clear understanding of what information is actually required, what this information is used for, and how the information can and will be employed.

Focus within the TOC is always upon those operations actually in progress or anticipated in the near future. Whether the situation is static or dynamic, the information that is processed and stored in any automated system serving the TOC should be that which is most current, has the greatest apparent value for the immediate direction of divisional elements, and the highest probability of use. Information of lesser apparent immediate value with only moderate probability of use during the next 12 hours, and information which relates to incidents that occurred at a reasonable period in the past can and should be migrated to an ancillary or slower storage medium. Information of little, if any, immediate value with little or no probability of use during the next 12 hours should be completely purged from TOS.

Segregation of battlefield information that appears very valuable and of great use from that which seems of moderate value and that which is marginal is complicated by the type and variety of the information that may be available and by the large number of sources from which such information can and does flow to the TOC. This sifting process can be eased, to a degree, if screening or pre-purging of some form is performed by major subordinate elements of the Division and by the managers of sensor systems and closed-loop weapons employment systems supporting or organic to the Division. Although lip service is given to the elimination of minutia at the lowest possible operating level, available communications frequently encourage higher headquarters to ask for excessive detail, while absence of clear doctrinal standards relating to optimal informational requirements for specific decision tasks now places no break on the quantity of information that may be forwarded to a Division headquarters, particularly from subordinate elements.

Essentially, intelligence information, relating to an opponent's physical presence, movement and intentions now presents the most difficult problem, albeit a welcomed one; since absence rather than a surfeit of such information was normally the rule in the past. What is now urgently needed is careful analysis to determine: (1) how much of what specific information, in what aggregate can be of greatest value to control major divisional maneuver elements; (2) what detailed information is required only in the closed loop weapons employment system for more effective target engagement and higher target kill probabilities; and (3) what fusion of sensor data can be best utilized for predicting enemy intentions and future actions. Properly performed, such analysis should lead to the development of pre-purging procedures appropriate for adoption with TOS and should contribute to a clearer understanding of what specific information should actually be handled by TOS. That analysis, however, is beyond the scope of this study effort.

Information relating to operations in progress and activity or movement that conveys indications of enemy intentions in the period 2 to 12 hours in the future is of greatest immediate value to the Division commander and his staff since this is the information to which they must respond with organic assets or for which they must request additional supporting assets. Information of both friendly and opposing forces is involved.

To control the maneuver of friendly elements, the Division commander and his staff are concerned primarily with the location of battalion sized aggregates and the effective combat strength of these units in gross terms (i.e., 75% effective with approximately 42 tanks or 90% effective with 50 tanks, etc.). Detailed friendly personnel and material status information is <u>not</u> continuously needed in the TOC. That type of information is handled by systems supporting personnel and logistical functions. Accurate updates of such information are normally acquired by appropriate division staff agencies through administrative channels once every 24 hours and can be furnished to the TOC on request. So far as battalion locations are concerned, these should be furnished whenever a battalion sized unit moves. Only current or planned future locations are needed, however; and new information should supplant old information which can be purged from TOS when the new information is received. Beyond this, a limited amount of certain other miscellaneous friendly information is also needed. This includes brigade CP locations, the position and extent of friendly minefields, planned nuclear or chemical targets, contact points between adjacent brigades, air defense installations, location of bridging equipment, the position of logistical support facilities, and the like. Such information is required essentially for movement coordination and control and should be held until supplanted by new data. Unfortuntely, locations mean little in textual format, but have immediate meaning for command and control when matched to, or displayed upon, a map or geographical representation of the battle area. Automatic graphical display of such material from the data base for the entire divisional area of operations appears to present the best method for depicting an overview of the situation, and can facilitate rapid identification of friendly and enemy force disposition changes. Such presentation can also materially assist the purging of outdated, erroneous or superfluous information.

Much of the data relating to the enemy during combat is, of course, a direct product of operations themselves. A great portion of this data can be used immediately to bring combat power to bear against the enemy. Such readily exploitable information is transmitted directly from the source or the point of origin to the user in real, or near real time. Army doctrinal literature relating to ground combat differentiates between this raw data on enemy forces and activity that can be used immediately upon receipt without interpretation or integration for tactical real time targeting and to direct maneuver from other enemy related data requiring validation, integration, comparison or analysis before use. The former is categorized as <u>combat information</u>, the latter <u>intelligence</u>. That data viewed as <u>finished</u> intelligence is <u>derived</u> from all available sources. It must be fused and analyzed before use, and is employed principally by higher command for planning, for moving and concentrating forces, and for limited targeting well behind the battle area. Although combat information must be rapidly fed to those combat leaders who can immediately use it, such information must also be transmitted upward in some aggregate to higher headquarters where the data can be processed into intelligence.*

Division headquarters' concern with information of the enemy focuses upon current enemy activity (activity that is occurring or has occurred within the previous hour) and enemy activity that can, and is likely to, occur in the next 12 hours. As with friendly information at the Division level, battalion aggregates are needed along with data on enemy nuclear delivery systems, etc. that are capable of inflicting major damage upon Division elements. Beyond that, interest centers primarily upon enemy dispositions and significant enemy actions and intentions that may influence operations of the Division projected for the next 12 to 24 hours. Information relating to given enemy force locations can be replaced by updated information as received. Supplanted enemy information can be immediately moved to a slower storage medium and completely purged from the system after a period of 12 hours. If needed for movement analysis of enemy units behind the immediate battle area, such information can be migrated to magnetic tape and then provided on that medium to intelligence agencies or higher headquarters requiring such historical data for order of battle determination and intelligence fusion and production. Data which has not changed that relates to enemy battalion sized units with which Division forward elements are in contact and to known enemy nuclear delivery systems capable of attacking the Division, should be held in the TOS data base as long as the location of such enemy forces are known and the Division operational area is unchanged. Data relating to enemy activity that terminated 6 hours or more in the past, can be automatically moved to a slower storage medium and data relating to enemy activity that terminated 12 hours or more in the past can automatically be migrated to separate storage medium (tape) and transmitted to Corps and above for possible analytical use.

Similar procedures can be utilized to handle data acquired by the closed loop weapons employment systems or sensor employment systems organic or attached to the Division. In principal, such information should also be removed from the information processing systems of those activities as soon as it is no longer of use for the battle at hand or for planning the next phase of the battle. Time thresholds for the migration of such data can be established based upon functional requirements of the activity or system concerned, as determined by actual field test

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* FM 100-5, pp. 7-4 and 7-5.

or exercise. Since aggregated information would be furnished to TOS by these weapons employment and sensor systems when the content was significant, no need exists to coincide thresholds for purging in such systems with those established for TOS itself. In general, however, like procedures can be employed with these sensor and weapons systems in migrating information no longer needed to slower access medium or to magnetic tape. Information that appears to have value for future analysis should be migrated to slower medium only if there is a reasonable expectancy that the information will be needed again in the near future (next 12 hours). Otherwise, the data should be stored on tape and disposed of after 12 hours.

In summary, then, so far as TOS is concerned, information kept in main storage should be that which appears of value for planning the next phase of the battle 12 to 24 hours in the future. The granularity of detail should be fixed by the operative parameters within which the Division commander and his staff function, i.e., if the commander is controlling brigade-sized elements and fire support priorities for brigade, details at company level are not required. Locations of enemy reserves (battalion size and larger) which can move to influence the current action or the next phase of the battle must also be recorded if known. Information relating to enemy activity 6 hours or older should be migrated to slower storage medium along with other information considered of interest but not essential for direction of such combat operations. Information 12 hours or older can be purged completely or placed on tape and physically dispatched to the next higher headquarters for appropriate use and disposition. This information is summarized in Figure 4-1.

The mechanics of actually handling data and of disposing of superfluous information can be systematically approached once the specific informational needs for command and control and functional management at division level are defined and agreement reached regarding the length of time such information remains useful and should be retained. Appropriate purging methods can then be matched to equipment capabilities and functional needs as well as to commanders' desires. A discussion of possible purging methods -- rules, techniques and operations -- that appear adaptable for this purpose is contained in the final sections of this chapter.

4.4 RULES, TECHNIQUES AND OPERATIONS FOR PURGING UNEEDED DATA FROM DIVISION TOS

Friendly force information required for command and control of Division units essentially constitutes a number of finite data sets which can be bounded arbitrarily to meet established functional needs without saturating existing communications facilities. Such information will normally either be furnished to Division headquarters on a continuous basis as specified data elements changes, or in aggregate form at prescribed

SUMMARY OF TOS INFORMATION PURGING CRITERIA

	ENEMY INFORMATION	
TYPE OF INFORMATION	DETAIL	RETENTION CRITERIA
1. Unit locations & dispositions (in contact and reserve)	1. Maneuver Units - Battalion aggregate 2. Supporting Artillery - Battalion locations (Divarty hold battery locations) 3. Nuclear Delivery Systems 4. Command Post locations - Division regiment and battalion - location 5. Special Units-Air Defense, bridging,etc.-location 6. Enemy minefields and obstacles - location	1. Hold while location and disposition remain unchanged. Replace when new information is received. 2. Replaced information migrated to slower storage medium and purged after 12 hours.
2. Current enemy activity and movement.	Same as above	1. Hold while in progress. 2. Migrate to slower storage medium when activity terminates or 6 hours afterward if retained for analysis and purge after 12 hours.
3. Information indicating enemy intentions for next 12 hours.	Same as above	1. Hold until applicable period has passed.

Figure 4-1.

SUMMARY OF TOS INFORMATION PURGING CRITERIA

TYPE OF INFORMATION	FRIENDLY INFORMATION DETAIL	RETENTION CRITERIA
1. Unit locations & dispositions.	1. Maneuver Units - Battalion aggregate. 2. Supporting Artillery - Battalion locations. 3. Nuclear Delivery Systems - location. 4. Command Post locations - battalion & brigade. 5. Supply points.	1. Hold while location & disposition remain unchanged. Replace when new information is received. 2. Replaced information purged as new information is received. 3. Purged information placed on magnetic tape. Used to prepare operations report in hard copy for 24 hour period then destroyed.
2. Movement, Obst Obstacles, and fire coordination features.	1. Contact points between brigades & with adjacent divisions. 2. Fire support coordination lines. 3. Friendly mine fields.	1. Hold while location remains unchanged. Purged when no longer valid. 2. Purged information placed on magnetic tape. Used to prepare operations report in hard copy for 24 hour period then destroyed. 3. For mine fields, hold until unit leaves area or minefield
3. Personnel and equipment status.	1. Maneuver, battalions supporting artillery, 4 nuclear delivery systems - percentage of fill personnel & major combat items. 2. Supply status - all class of supply days of supply available.	1. Hold until status changes. Changed once daily or more often if warranted. 2. Replaced information purged as new information received

Figure 4-1 continued.

periodic intervals. Information dynamically updated will relate principally to tactical deployment and maneuver, and should be comparatively limited in quantity; that provided at periodic intervals will mainly be employed for logistical and administrative purposes and may be greater in quantity. Thus, careful analysis of actual informational needs and judicious development of reporting procedures can result in precise delineation of the actual quantities of data that must be gathered and that will be stored in automated support systems. In a sense, such procedures will serve much the same as pre-purging, but in a way that insures that specified information always is available. This will permit accurate determination of that quantity of computer storage capacity that must be reserved for friendly information. Actually, however, only friendly information that is dynamically updated need be kept in the TOS main storage memory. Data updated periodically can be held in hardcopy or on slower storage memory, or possibly on tape. When periodic updates are received, suitable file maintenance of automated files can then be accomplished using main storage, and only the appropriate summaries either printed out or held in main storage while the data file in its entirety is returned to a slower storage medium.

Enemy information represents a different problem, however, since it constitutes a number of indefinite data sets which can involve varying degrees of uncertainty and completeness. In part, the amorphous nature of enemy related information results from a combination of the low probability that all enemy elements will ever be detected and their intentions accurately determined by friendly forces; and from the existence of misleading data and observations resulting from misperceptions, erroneous reports or enemy deceptive measures. Thus, enemy information will constitute the most elastic quantity with which TOS must deal. At one time, TOS may be inundated with enemy information; at another the quantity of such information may be extremely small. This seems to suggest that somewhat different purging rules may be required for enemy information when large quantities are available as opposed to when data is scarce, and that through use of computer prompting techniques TOS analysts might be aided in sorting large data volumes.

A variety of possible methods exist which can be employed to control and manage the various data that will be processed and stored in TOS. In all probability, no single method for purging can fully meet all the dynamic needs of such an operational information system. With this in mind, those principal methods which appear most appropriate are discussed in general terms below. Actual experimentation with various combinations of these methods in an exercise environment should permit identification of an optimal mix for TOS operations.

4.4.1 Prepurging or Elimination of Extraneous Information Before Entry Into Automated System

As discussed in Section 4.3, aggregation of selected data by major subordinate elements and sensor managers reporting to the TOC can result in substantial reduction of information storage requirements. Parameters for aggregation should be based on accepted doctrinal requirements for tactical decision at the level involved. Thus, for the Division TOC, friendly and enemy maneuver units would be identified only in battalion sized groupings, and locations of command installations need be held only for battalions, brigade, regimental and division sized units. Division artillery elements concerned with identification and engagement of individual targets by indirect fire would provide aggregate information on fire support only when change of fire priorities appeared warranted, when a summary of fire support results was desired, or the use of nuclear weapons contemplated. Coordinating information such as boundaries, fire support coordination lines, etc. would be entered into TOS only for those major elements of the division under direct division control. Data would be held on a limited number of selected friendly and enemy elements such as nuclear delivery units, bridging elements, air defense units, etc. in accordance with a Division commander's specific desires and guidance. Tracking of minor units should, however, be limited to those of vital significance to the Division's overall missions. Detailed intelligence information such as order of battle, would be managed by those intelligence agencies supporting the Division, and only aggregated information would be forwarded to the TOC for entry into TOS. This would occur when such information reached thresholds previously designated by the Division commander.

Prepurging can also be employed to eliminate most information from TOS which relates to activity that falls outside the geographic area of the Division commander's most immediate concern (his zone of influence) -- an area slightly wider than the Division sector and extending 25 to 35 kilometers beyond the forward edge of the battle area. In this case, the Division commander is also interested in all enemy battalion sized elements and larger, both to the flanks of his Division and beyond the Division zone of influence that could be employed in his operational area within a time window of 6 to 8 hours. However, information on these elements need not be entered into TOS until they cross the boundary into the division's zone of influence. This particular technique can be of greatest use in handling information of friendly force status and disposition and relating to coordination; that normally is passed via command communication nets and handled primarily by operations personnel (G-3 and S-3 Sections).

4.4.2 Automatic Purging or Elimination of Information in Accordance with Established Criteria

Removal of information from the TOS data bank can be accomplished automatically in accordance with a number of different parameters. For example, as discussed in Paragraph 4.3, information can be moved from main storage memory a given period of time after an incident or event has terminated or can no longer be observed, and either placed in slower storage medium or completely purged; or information pertaining to a given geographic area might automatically be removed from the data base if the area was no longer of concern to Division operations. Such removal, of course, requires a measure of judgment in the creation of algorithms suited for purging data no longer of value, while retaining that which is needed and can continue to be used for decision at Division level. Another possibility might involve the elimination of the oldest information or given types of information from main storage when the computer storage capacity reaches a given state of fill (i.e., 90% or 95% full). Again, prudence dictates that such automatic mechanisms be designed so that information with apparent value to the operations be retained. Obviously, an automatic purging system will be acceptable to users only if they are convinced that elimination of information will be accomplished in such a way as to aid their continued task performance and not destroy or dispose of information which the system operators or the input agencies have exerted considerable effort to place in the automated system and which still seems to have value for the tasks at hand. Further, the psychological implications of rigidly set purging criteria which users cannot readily adjust are profound. For acceptance, local modification of algorithms must also be possible to meet differing operative conditions, individual perceptions and combat environments. Automatic purging can be employed for both enemy and friendly information handled principally by intelligence and operations personnel (G-2 and G-3 Sections). In the case of enemy information, however, since the combat information entered into TOS may be required later for intelligence production at Division level and above, G-2 related or created information can be migrated to auxillary storage (tape) for future use as needed, with copies of the tapes passed to interested higher headquarters.

4.4.3 Selective Purging of Data Based Upon Substantive Values Assigned by Operators as Input Agents when Data is Entered into System

Criteria can be established for coded identification of information at the time of entry into an automated system. As an example, data could be classified by analysts at the TOC into categories reflecting judgment as to the likely value of a given piece of information, and the probable period of time or the conditions under which this information would retain such a value. When the identified period of time has passed, or when conditions associated with assigned value have changed, or when acquisition of more information might dictate, stored information could be purged in aggregate lots upon operator initiative. Such might be achieved by eliminating an entire category or classification, or by eliminating items selectively from a specific category. A large number of such schemes are possible. All, however, require involvement of the system operators, demand exercise of judgment on the part of those inserting or purging information, and tend to be more time consuming than fully automated purging methods. As with automatic purging discussed previously, information being removed from the system can be placed on auxillary storage medium although it is more likely that information being selectively purged would be destroyed rather than saved. Thus, though such techniques can be employed by both intelligence and operations personnel (G-2 and G-3) applicability appears most likely for information that relates to activity that occurs or is planned within a specific timeframe such as friendly patrol activity, friendly aerial or ground reconnaissance, unit displacement, supply point closure, etc.

4.4.4 <u>Purging of Data by Means of Updating or File Maintenance Procedures</u>

Whenever data is supplanted by new or more current information related to a given incident, an activity, physical presence, etc. the data that is being supplanted can be automatically purged from current holdings. This is a normal procedure used in updating batch data processing applications that can also be adapted for TOS. Thus, when the location of a friendly or enemy battalion changes the new location for that unit would be entered into the data base automatically supplanting the old. This can be accomplished in such a way so as either to retain what is removed by placing data being supplanted on slower storage medium or to eliminate it completely. Such procedures are most easily employed with formatted messages where data is filed in fixed fields, and only specific items of information are changed rather than the entire file or message. However, through careful design of input message or data format proper indexing can permit replacement or purging of one entire message by another, if desired. This automatic replacement through use of file maintenance procedures is particularly suitable for information that is updated at stated periodic intervals such as personnel and equipment status records (G-1 and G-4). With this type of record the file maintenance process is normally performed at given intervals. However, if the information is continuously retained in main storage such update can be performed dynamically whenever new information is received. Thus, such automatic replacement could be employed to handle intelligence and operations data as well (G-2 and G-3).

4.4.5 Analyst Purging on a Selective Basis

A variety of procedures can also be adapted to facilitate analyst reduction of data holdings on a selective basis. Given specific types of data, holdings might be reexamined by analysts periodically and a decision made in each case regarding whether the information in question should be retained, moved to a slower storage medium or completely purged. If in message format, such information could be displayed upon a viewing device (cathode ray tube, plasmascreen, or the like) for easy viewing, and then disposed of as deemed appropriate by the analyst.

Actual purging might be performed by all parties who have devices with access to the data base, or such activity might be restricted to specified individuals. Analyst purging of information relating to unit locations, movement, etc. can be accomplished comparatively easily if such information is electronically displayed using symbol representations on an electronic viewing device, where the activity, unit, etc. is portrayed on a scaled representation of the battle area. In such a case, the analyst can view the information, determine whether or not the data should be retained and then using either keyed instructions, a "light pen", a touch panel, etc., eliminate the specific information that is no longer desired. Such dynamic display of tactical information superimposed over a map representation appears to offer an ideal mechanism for comparing observable events quickly with the planned conduct of the battle. These techniques are suitable for use by all agencies or staff personnel normally placing information into TOS and/or using information being processed by that automated system (G-1, G-2, G-3 and G-4).

4.4.6 Purging Based Upon Frequency of Information Use

A logical case can be made that information placed in an automated system to support operations is superfluous to immediate needs if no reference is made to this information. Accordingly, such data might be eliminated from a data base after a period of time when it appears that no use has been made of the information. This can be accomplished automatically after a given period of time, or can be done on analyst command after passage of some temporal limit. In either case, the information system must be so structured as to record each reference made to the data holding in question so that information referenced frequently can be readily identified and separated from that which receives little or no use. Since completely automatic purging based solely on use may not be readily acceptable to analysts, provision can be made for them to view the information that has had little, if any, use before it is dumped from the data base. This technique can also be employed by any analysts who have access to TOS and are inputing data or using data in the system

(G-1, G-2, G-3 and G-4). As with all the techniques discussed in this section, particular application will be a function both of system design and configuration and conceptual use.

4.4.7 Purging to Protected Informational Content

Some mention must be made of the unique requirement to be able arbitrarily to remove all information in the TOS system and destroy the data in event of an emergency. Such an expediency would not be employed to manage the volume of information, but as a safety device to insure that information held in the automated system could be physically disposed of quickly in order to prevent the information from falling into an opponent's hands when capture of the TOC appeared imminent. This is essentially a procedural matter, but one that deserves consideration. In any case, this type of purging would normally be accomplished only on command. Short of the ability to remove the data holdings, the automated storage devices could, of course, be physically destroyed with explosives or incendiary devices.

Chapter 5

METHODS FOR EVALUATING PURGE PROCEDURES

To select appropriate methods for evaluating purge technological innovations it is first necessary to establish certain criteria which such methods must satisfy. These criteria are the subject of Section 5.1. Section 5.2 presents a review of traditional methods which have been used to assess the relative and absolute merits of technological innovations. These methods are then critiqued in Section 5.3 in light of the fundamental criteria established in Section 5.1. Section 5.4 concludes the chapter with recommendations for evaluation methods to be utilized in the further study of purge alternatives.

It should be emphasized that the evaluation methods described here are primarily concerned with the selection of a purge algorithm for implementation or possibly for full scale testing. These methods rely on concepts of efficiency and require as input certain information pertaining to benefits, costs or utility. Their heritage is in the literature of economics and operations research. As such, the methods of this chapter are not to be confused with methods for evaluating ongoing applications which have been described in the psychological literature. The latter emphasize protocol for gathering information necessary to perform evaluations and tend to stress institutional and behavioral factors. Presumably the information needed to establish the efficiency of a given purge alternative is already available before the methods of this chapter are applied. When new or conflicting information is uncovered by the evaluation of an ongoing application, its effect on the rank ordering of alternatives as determined by the methods of this chapter should be investigated.

Because of the nature of this chapter it is useful to introduce a model of purge operation which is somewhat more detailed than that discussed in preceding chapters. This model is depicted in the flow diagram of Figure 5-1. Although largely self-explanatory, elements of this model will be discussed in detail in the sections which follow.

5.1 CRITERIA FOR SELECTING AN EVALUATION METHOD

The entire concept of purging data is predicated on the belief that certain types of information are more important than other types, and that these more important types of data can, in fact, be identified. It is convenient to refer to this point of view as the "concept of essential information". It may be said that one criterion a purge evaluation method must satisfy is that it be compatible with a reliable approach for defining essential information.

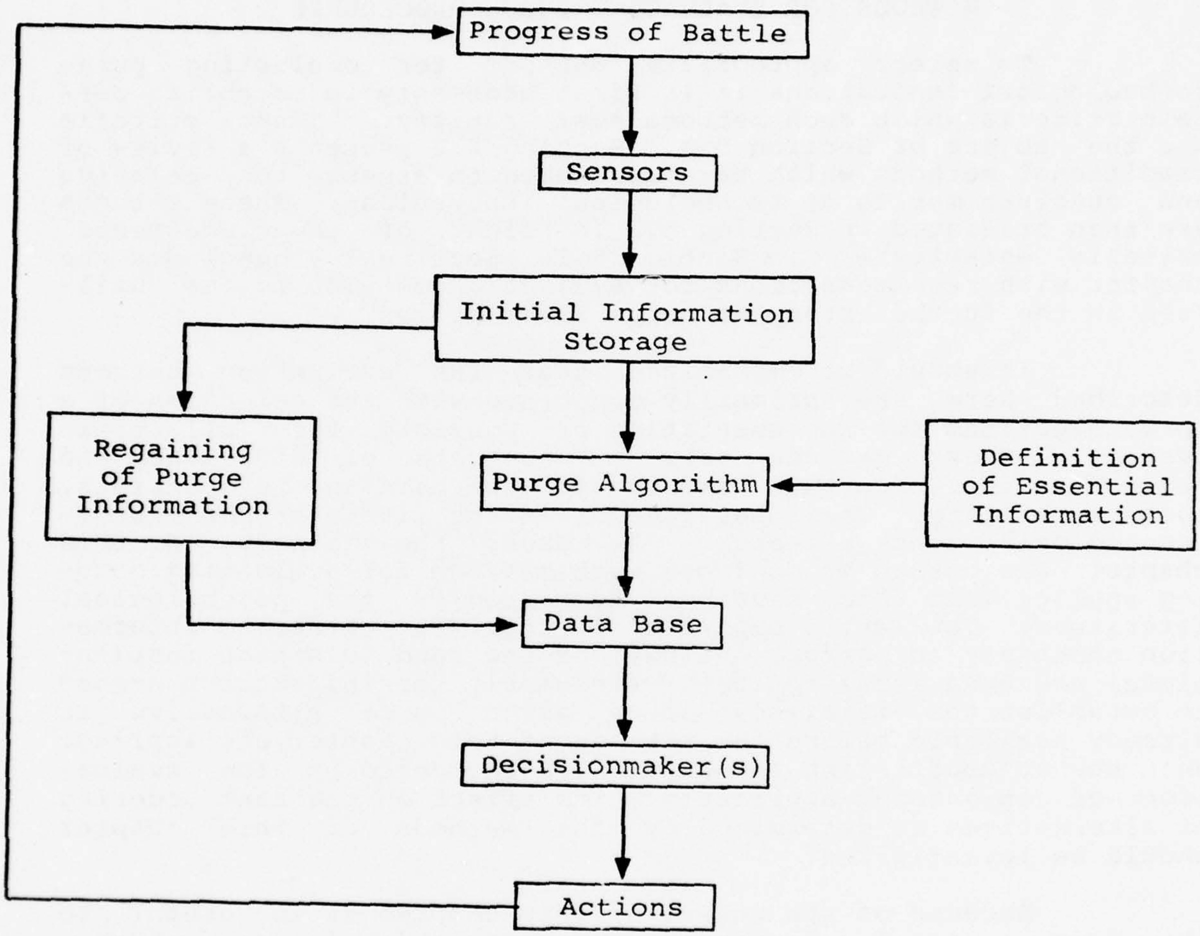

Figure 5-1. Conceptual Model of Purge Operations

Any evaluation method will require that certain information be input to it. A method which requires input data which does not exist or cannot be obtained is useless. Thus, a second general criterion for purge evaluation methods is a requirement that important data necessary to the application of a given method be readily available.

Typically, any evaluation method will characterize -- either implicitly or explicitly -- the best alternative as that which maximizes some objective function, i.e., gives the highest value of some measure of system performance. Thus, a third criterion which an evaluation method must satisfy is that of possessing both implicit and explicit system performance measures, or objectives, which accurately reflect the objectives of system users.

Moreover, it is very likely that multiple objectives for the operation of a purge system will exist; this phenomenon is a direct result of the fact that different user groups, in particular different military command levels and functional elements will specify different objectives for the operation of a purge system. Because of such factionalism, a fully state-of-the-art evaluation procedure ought to be able to address multiple system objectives.

5.2 METHODS FOR EVALUATING TECHNOLOGICAL INNOVATIONS

Five traditional methods for evaluating technological innovations have been selected for review. These are:

TYPE 1. Benefit-cost analysis;

TYPE 2. Cost-effectiveness analysis;

TYPE 3. Decision analysis;

TYPE 4. Multiattribute analysis; and

TYPE 5. Multiobjective analysis.

These methods were selected because of their widespread use in all types of technology evaluations. Moreover, the evaluation approaches chosen provide a natural typology for evaluation techniques in general. Table 5-1 presents such a typology; movement down the table corresponds to increasing sophistication, e.g., the addition of risk, nonlinear utility, or some other element not considered in lower order evaluation methods. A table similar to this was first suggested by de Neufville and Marks.[1]

[1] de Neufville, R. and Marks, D. Systems Planning and Design Englewood Cliffs, New Jersey: Prentice-Hall, 1974.

Table 5-1. Typology of Evaluation Methods

TYPE	METHOD CHARACTERISTICS				ISSUES
	Non-Linearity	Multi-Attribute	Includes Risks	Multiple Objectives	
1	No	No	No	No	linearity single numeraire no explicit consideration of probabilistic events discount rate investment criteria benefit estimation
2	Yes	Yes	No	No	non-linearity multi-attribute preference estimation single objective
3	Yes	No	Yes	No	single numeraire estimation of subjective probabilities single objective
4	Yes	Yes	Yes	No	multi-attribute preference estimation estimation of subjective probabilities single objective
5	Yes	Yes	Yes	Yes	theory of welfare economics

5.2.1 TYPE 1: Benefit-Cost Analysis

The literature on benefit-cost analysis is enormous. Space does not permit and necessity does not warrant a comprehensive review of that literature. It will suffice to highlight the more significant assumptions which go into the method.

As indicated in Table 5-1, traditional benefit-cost analysis proceeds from the following assumptions:

- the value of any benefit is assumed to be proportional to the amount of that benefit. That is, if a technological innovation saves 10 man hours, the value of that savings (benefit) is twice that of an alternative innovation which saves 5 man hours;

- notions of probability need not be incorporated explicitly and it is appropriate to use expected values;

- there is but one dimension to benefits and costs. That is, all the several dimensions of benefits and costs may be collapsed and measured as one dimension or attribute. That measure is typically taken to be money. A benefit or cost which is not reducible to monetary terms is not considered; and

- there is but one decisionmaker. That is, all parties to the decision of whether to implement a particular technological innovation are agreed upon a single criterion for evaluation, or objective. The objective is typically the maximization of net benefits, without regard to which parties they accrue.

Benefit-cost analysis is performed according to an extremely simple paradigm: benefits and costs for each time period of interest are reckoned in terms of a common numeraire for some base time period and compared. There are a variety of methods of comparison, all of which are concerned, in one fashion or another, with whether there is an excess of total benefits for all time periods over total costs for all time periods. Clearly, such a paradigm requires that one be able to express the value of a known amount of benefits in a future time period in terms of the numeraire during the chosen base time period. This is accomplished by introducing the concept of a discount rate. A discount rate i (assuming money as a numeraire and the year as an increment of time) is an expression that \$(1+i) a year from today has the same value as \$1 today.

A principle issue involved in the conduct of benefit-cost analysis according to the paradigm described above is that of selecting an appropriate discount rate. The discount rate is typically given in terms of a percent per year, and as stated previously, is the measure by which it is possible to compare different benefits and costs in the time stream. As such its value is of critical importance. A discount rate which is lower than appropriate will frequently lead to the overestimation of net benefits; a rate which is too high may lead to underestimation.

Criteria for establishing the appropriate discount rate have not been agreed upon. However, a widely accepted principle for determining such rates is the "opportunity cost principle". The so-called "opportunity rate of discount" is that rate of growth which funds would exhibit if used in the "best alternative" beside the innovation being considered. In this definition, "best alternative" is subject to a variety of interpretations, but is frequently taken to mean investment in the private sector. A more complete discussion of the various schools of thought on the subject of selecting an appropriate discount rate is given by Friesz.[2] Department of Defense policy concerning the selection of a discount rate is described in DOD Instruction No. 7041.3.[3]

Once the discount rate is decided upon, it is necessary to select an appropriate ranking measure, i.e., a criterion for determining feasibility and ranking alternative innovations. The literature commonly refers to such ranking measures as investment criteria, for they serve as indicators of whether a given innovation is feasible and of that innovation's likely performance relative to other innovations. In the benefit-cost literature, the most common investment criterion is that of maximizing the present value of net benefits (that is, selecting the innovation with the highest such value). This criterion may be expressed in at least four equivalent ways provided the following are true[4] :

- alternative innovations are not interdependent or mutually exclusive;

- planning horizons for all alternatives are coincident; and

- no constraints of a budgetary or other nature exist.

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[2] Friesz, T.L. "Discount Rates for the Benefit-Cost Analysis of Public Projects". Science Applications, Inc. Report No. SAI-76-550-WA, 1976.

[3] ___________. Economic Analysis and Program Evaluation for Resource Management. Department of Defense Instruction No. 7041.3, October 18, 1972.

[4] Prest, A. R. and R. Turvey. Cost-Benefit Analysis: A Survey, in Surveys of Economic Theory , Vol. III. New York: St. Martin's Press, 1966.

If these requirements are met, the single criterion of maximizing the present value of net benefits may be expressed in the following equivalent fashions:

- select the project with the highest present value of benefits less the present value of costs, provided such difference is positive;

- select the project with the highest ratio of present value of benefits to present value of costs, provided such ratio is greater than unity;

- select the project whose constant annuity with the same present value as benefits most exceeds the constant annuity (of the same duration) with the same present value as costs; and

- select the project with the highest internal rate of return above the appropriate rate of discount for annual compounding.

A more complete discussion of investment criteria is given by Friesz.[5]

The procedure of benefit cost-analysis then is to evaluate alternative innovations according to one of the criteria of Table 5-2; the innovation which gives the highest criterion value is judged "best".

As has already been noted, a major stumbling block in the application of benefit-cost analysis, as it has been described here, is the difficulty that exists in estimating the dollar benefits of alternative innovations. Generally speaking, the benefits from a technological advance are most naturally measured in a number of diverse units, e.g., time saved, increased reliability, better user acceptance, etc. If benefit-cost analysis is to be utilized these non-dollar benefits must be translated into dollar terms. This is the so-called problem of the single numeraire mentioned in Table 5-1 for TYPE 1 evaluation methods. Such reduction to dollar terms may not always be possible without making severe assumptions.

In summary, it may be noted that as a TYPE 1 evaluation methodology benefit-cost analysis is hampered by weaknesses on several major fronts: it assumes a single numeraire exists (dollars); estimation of the discount rate is subject to controversy; the determination of benefits is at best difficult; if budget

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[5] Friesz, T.L. "Investment Criteria for the Benefit-Cost Analysis of Public Projects". Science Applications, Inc. Report No. SAI-76-551-WA, 1976.

CRITERION	MATHEMATICAL STATEMENT
Net Present Value	$\frac{b_1}{(1+i)} + \frac{b_2}{(1+i)^2} + \dots \frac{b_n+s}{(1+i)^n} > \frac{c_1}{(1+i)} + \frac{c_2}{(1+i)^2} + \dots + \frac{c_n}{(1+i)^n}$
Ratio	$\dfrac{\frac{b_1}{(1+i)} + \frac{b_2}{(1+i)^2} + \dots + \frac{b_n+s}{(1+i)^n}}{\frac{c_1}{(1+i)} + \frac{c_2}{(1+i)^2} + \dots + \frac{c_n}{(1+i)^n}} > 1$
Constant Annuity	$b > c$
Internal Rate of Return	Select projects where $r > i$, where r is given by $\frac{b_1-c_1}{(1+r)} + \frac{b_2-c_2}{(1+r)^2} + \dots + \frac{b_n-c_n}{(1+r)^n} = 0$

Key: $c_1, c_2, \dots, c_n$ = Series of prospective costs in years 1, 2,..., n

c = Constant annuity with same present value as $c_1, c_2, \dots, c_n$

$b_1, b_2, \dots, b_n$ = Series of prospective benefits in years 1, 2,..., n

b = Constant annunity with same present value as $b_1, b_2, \dots, b_n$

s = Salvage value

i = Appropriate rate of discount for annual compounding

r = Internal rate of return

Table 5-2. Symbolic Statement of the Four Primary, Equivalent Investment Criteria constraints exist or if the innovations considered are interdependent, special investment criteria must be developed; the "value" of an innovation is assumed to be proportional to its amount; and probabilistic considerations are not taken into account.

5.2.2 TYPE 2: Cost-Effectiveness Analysis

The terminology "cost-effectiveness analysis" is widely used to describe virtually any form of analysis that considers the costs and performance associated with a technological innovation. Here the terminology will have a much more explicit meaning:

> Cost-effectiveness analysis refers to the evaluation of technological innovations by measuring costs in terms of dollars and effectiveness (or performance) in terms of a multiattribute utility function. The innovation, then, which provides the greatest utility per dollar expended is the most attractive.

Quite clearly, in order to perform an analysis of this type it is necessary to be able to estimate the multiattribute utility function described above. A multiattribute utility function may be described symbolically as:

$$U_t = f(x_1, x_2, \ldots x_n; t), \tag{1}$$

where the x_i are attributes or variables describing a technological innovation and t is an index denoting the t^{th} year. Given values for the variables x_i, equation (1) provides a number describing the utility of a particular innovation. Since each innovation in general will be characterized by different values for the attributes x_i, each innovation will possess a different utility.

Furthermore, each set of values for the attributes (x ,x ,....x) will represent a particular cost; hence the cost in year t, denoted by C , of any innovation may be determined from a relationship of the form

$$C_t = g\ (x_1, x_2, \ldots x_n; t). \tag{2}$$

Relationship (2) is essentially a parametric cost equation similar to those one would develop in the parametric cost analysis of a given technology.

similar to those one would develop in the parametric cost analysis of a given technology.

A measure of the cost-effectiveness of a given innovation in year t is obtained by taking the ratio

$$\frac{U_t}{C_t} = \frac{f(x_1, x_2 \ldots x_n; t)}{g(x_1, x_2 \ldots x_n; t)} \tag{3}$$

This ratio may be interpreted as an approximation of the marginal utility with respect to total cost of the innovation of interest. A measure of cost-effectiveness over a planning horizon of T years must involve some form of discounting as was encountered in the TYPE 1 benefit-cost evaluation methodology. If i is an appropriate discount rate, then a criterion for ranking innovations according to their cost-effectiveness is:

$$\Gamma = \frac{\dfrac{U_1}{(1+i)} + \dfrac{U_2}{(1+i)^2} + \ldots\ldots + \dfrac{U_n}{(1+i)^n}}{\dfrac{C_1}{(1+i)} + \dfrac{C_2}{(1+i)^2} + \ldots\ldots + \dfrac{C_n}{(1+i)^n}} \tag{4}$$

The innovation with the highest value of Γ as expressed by (4) would be judged the most cost-effective. Note, however, that unlike benefit-cost analysis this approach does not provide any feasibility criterion. That is, in benefit-cost analysis, if the ratio of benefits to costs (see Table 5-2) is greater than unity a project is feasible (but not necessarily optimal); no parallel criterion exists for the cost-effectiveness measure Γ given by (4). The lack of such a criterion is a serious handicap; it means that one may be able to select the optimal innovation from among a set of innovations, but, paradoxically will not be able to determine whether that optimal innovation is feasible.

5.2.3 TYPE 3: Decision Analysis

The process of decision analysis is conceptually simple. First, all possible sequences of decisions are laid out. Since there can be several choices at any state, and since each choice may branch into several consequences, it is common to speak of this representation as the decision tree. Second, all possible outcomes are indicated together with the apriori probability of occurrence. Next, the utility function of the decisionmaker is assessed, and the utility or real value of each outcome is calculated. Finally, the optimal choice at each stage, and thus the optimal sequence of choices, is calculated on the basis of maximizing the expected value of utility.

A critical element of decision analysis evaluation approaches is that they employ procedures to quantify an individual's utility. Typically, these utilities are of a single attribute nature and depend solely on the amount of money realized from a particular action. Often rather than go to the trouble of articulating a utility function, some analysts use the expected dollar value of alternatives as a ranking measure.

To illustrate a single attribute utility measure, consider

$$U(x) = 1 - e^{\lambda x}, \tag{5}$$

where x represents the monetary value of an outcome and λ is a measure of risk aversion. Expression (5) is a common utility measure which has been found to fit a wide range of individuals when faced with lottery decisions which have the same selling and buying price for entrance.[6] It should also be mentioned that when expected dollar value is used as a ranking measure one has implicitly assumed a utility function of the form $U(x) = x$ where x is the net dollar value of a given outcome.

The application of decision analysis to the evaluation of purge alternatives is perhaps best illustrated by an example. Suppose in a given military environment one is faced with the decision of whether to purge information. For the sake of simplicity assume there are only two purge techniques of interest and that no new data will be input or requested during the time period being considered. Thus, at the outset one must choose from among three courses of action:

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[6] Raiffa, H. Decision Analysis: Introductory Lectures on Choices under Uncertainty. Reading: Addison-Wesley, 1970.

- do not purge -- denoted by e_0;
- purge using technique 1 -- denoted by e_1; and
- purge using technique 2 -- denoted by e_2.

Each purge decision will lead to an environment in which certain chance events may take place. For this example assume that the first such set of events to occur following the initial purge decision is described by:

- no encounter with enemy forces -- denoted by f_0;
- encounter with enemy forces and required information is available in ready storage -- denoted by f_1; and
- encounter with enemy forces and required information is not available in ready storage -- denoted by f_2.

The probabilities that each of these events will occur differs, of course, according to which purge alternative was initially selected. Let p_{ij} denote the probability of encountering chance event f_j when purge alternative e_i was selected.

Clearly, if no enemy forces are encountered then there is no question of whether the outcome was a success. For other types of encounters (f_1 and f_2) there is a probability $q_{k\ell}$ that encounter k will lead to outcome ℓ where the outcomes are comprised of the following set:

- no encounter -- denoted by r_0;
- successful encounter --denoted by r_1;
- encounter was a failure -- denoted by r_2; and
- encounter was a draw -- denoted by r_3.

If one introduces the quantities V_{r_0}, V_{r_1}, V_{r_2} and V_{r_3} to refer to the net cost in dollars (taking into account the initial costs for each purge approach) of the respective outcomes r_0, r_1, r_2 and r_3, then the simple decision tree of Figure 5-2 may be constructed. This figure describes all combinations of purge alternatives and chance events. The expected cost of each individual outcome is computed by multiplying the appropriate "encounter probability" p_{ij} by the appropriate "outcome probability" $q_{k\ell}$; this product is in turn multiplied by the appropriate outcome cost to determine the expected outcome cost. Expected outcome costs are added for each purge alternative to get the expected net costs described in Figure 5-2. The alternative with the lowest expected net cost is the most desirable.

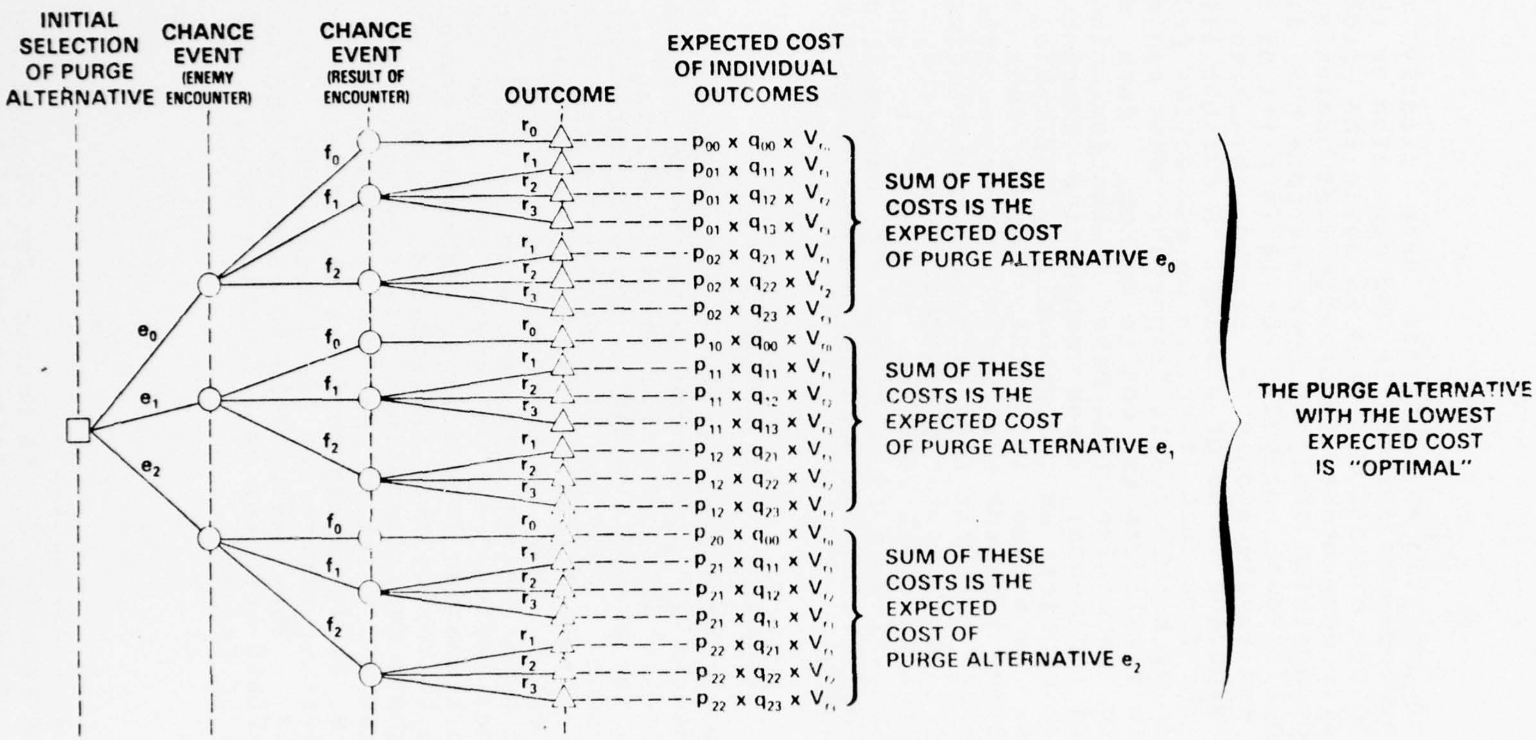

FIG. 5-2. EXAMPLE DECISION TREE

Decision analysis as outlined here clearly requires that either all outcomes be apriori in one dimension or that they be translated into one dimension. This is again the problem of the single numeraire encountered in benefit-cost analysis. As an evaluation method, decision analysis does overcome the linearity restriction of benefit-cost analysis, yet it is still of a single attribute nature and involves only a single objective, namely maximizing the expected value of utility. A further limitation of the method is the fact that it relies on subjective probabilities articulated by knowledgeable "experts". This subjectivity is felt by some to invalidate the entire method. Such critics, however, fail to recognize that other evaluation methods also involve subjective judgments; these subjective characteristics are perhaps not as explicit as the probability estimation task of decision analysis. As a case in point, benefit-cost analysis makes the subjective judgment that maximizing net economic benefits is the "correct" criteria for evaluating technological innovations. Moreover, as typically practiced, benefit-cost analysis subjectively assumes that all benefits, no matter to whom they accrue, ought to be weighted identically. The essential point is that all traditional evaluation methods involve subjectivity in one form or the other.

5.2.4 TYPE 4: Multiattribute Analysis

In many circumstances, it is not at all clear how the multiple consequences of a given choice are to be compared; that is, a common numeraire does not exist which is meaningful to the situation. What, for example, would be the most satisfactory way to compare the several dimensions of a proposed purge technological innovation: capital cost, lives saved on the battlefield, user acceptance, etc.? There is no doubt, as everyday experience illustrates, that human beings integrate such multiple attributes describing outcomes influenced by a given innovation and make choices between alternative innovations. Extensive psychological literature exists to verify that individuals integrate multiple attributes in their decisionmaking; this literature is reviewed in detail in Friesz and Skiscim.[7] Moreover, Friesz and Skiscim have conducted a study which verifies that multiple attribute information integration occurs for field grade Army officers in combat situations. They were able to estimate the utility of particular battlefield outcomes as a function of 14 attributes describing status of forces.

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[7] Friesz, T.L. and Skiscim, C. "A Metric for Evaluating Human Decisionmaking Performance". Science Applications, Inc. Report No. SAI-77-698-WA, 1977.

Although the work of Friesz and Skiscim resulted in a linear utility function, multiattribute evaluations in general attempt to account for the nonlinear, nonadditive nature of an individual or a group's utility. Once a multiattribute utility function is obtained through statistical inference, it may be used in the evaluation process just like a single-attribute utility function is used in traditional decision analysis. Thus, one may speak of multiattribute decision analysis, or, as it is termed here, simply multiattribute analysis.

Recall that the framework of decision analysis, whether single or multiattribute, provides a powerful extension over the TYPE 1 and TYPE 2 evaluation methodologies in that it explicitly and systematically accounts for risk. Because decision analysis by its very nature focuses on the preferences of the individual, it is best suited for those situations in which the individual makes choices, i.e., for which the individual is the decisionmaker. By extension, decision analysis may be applied to situations in which the individual is a representative member of some homogenous, like-minded group. Consequently, decision analysis is not appropriate for situations in which individuals are in conflict. Said differently, unless group consensus regarding an appropriate single or multiattribute utility measure exists, decision analysis appears inappropriate.

5.2.5 TYPE 5: Multiobjective Analysis

The techniques of multiobjective analysis are the most recent to enter the process of implementation. These procedures attempt to lay out explicitly the preferences of the conflicting groups concerned with a given technological innovation for all sets of possible consequences. In this way, these techniques strive to allow the analyst to estimate what choices are preferable to several groups, and how differences might be resolved. The unique, but almost transparently necessary, feature of multiobjective analysis is that it articulates all initial objectives and all consequences of any decision with respect to the interest groups included in the model description. Theoretically any finite number of interests may be handled by multiobjective analysis, which is based on extensions of the more commonly known single objective techniques of mathematical programming.

In its simplest form the process of multiobjective analysis involves two analytical stages. First the maximum levels of attainment along the several dimensions or attributes of the consequences are calculated. This defines what is known as the transformation curve (or surface). Second, the analyst is supposed to describe the isoutility[8] curves that characterize indifference of the several parties involved in the decision or evaluation. These two stages are combined by seeking the points of tangency of isoutility curves with the transformation curve

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[8] Note that isoutility curves are merely plots of constant utility for a particular decisionmaker.

evaluation. These two stages are combined by seeking the points of tangency of isoutility curves with the transformation curve (also frequently called the trade-off curve). These points are the respective optima for each interest group. One then seeks a value of the project attributes representing a point on the transformation curve which comes as close to achieving the individual optima as possible. The process is reflected in Figure 5-3 for a two objective problem involving maximization of dollar savings and the maximization of information completeness. This technique is discussed in detail by Marglin.[9]

Transformation curves are difficult to specify and it is desirable to have a reliable, systematic technique for constructing such curves. Multiobjective linear programming provides a technique for generating transformation curves which is useful in a wide variety of circumstances. This alternative is described in detail in Appendix D. Suffice it to say that multiobjective linear programming stands on a sound mathematical foundation and may be applied to the multiobjective analysis of alternative innovations, provided group utility functions are linear. The linearity of such utility functions for field grade Army officers in combat situations has been demonstrated by Friesz and Skiscim; it is not unreasonable to expect such linearity to be exhibited for other command levels across all the military services. If this is the case, multiobjective linear programming represents a powerful analytical tool for the evaluation of alternative purge (as well as other military) technological innovations.

Multiobjective analysis, then, represents a radical departure from the previous evaluation methods for it assumes conflict and seeks the simultaneous maximization of each group's utility function. As such, it does not attempt to impose or prescribe technological solutions, but rather to articulate in an explicit fashion all the trade-offs involved in any decision to implement a particular technological innovation.

5.3 CRITIQUE OF EVALUATION METHODS

This section will present a very succinct critique of the evaluation methodologies presented in the previous section. The criteria followed in this critique will be primarily those set forth in Section 5.1. It will be recalled that those criteria are:

CRITERION 1. Compatibility with a reliable approach for defining essential information.

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[9] Marglin, S. <u>Public Investment Criteria</u>. Cambridge: MIT Press, 1966.

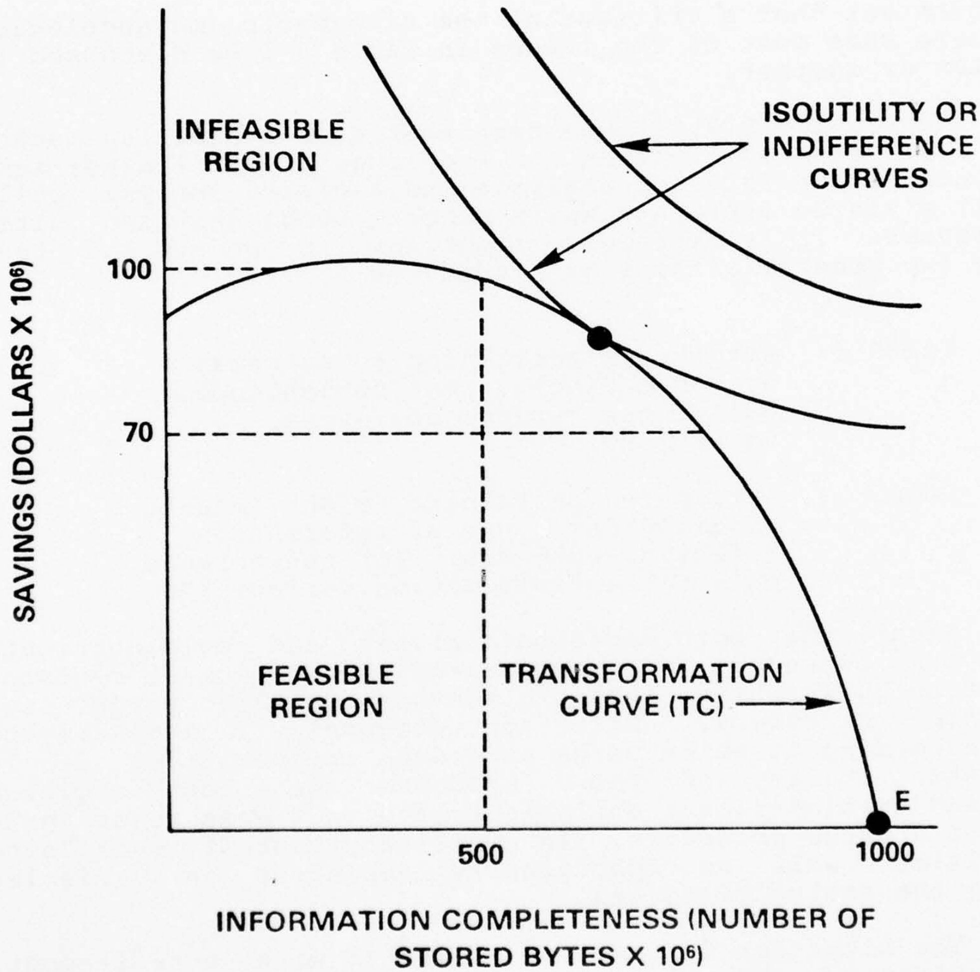

Figure 5—3. Graphical Representation of a Multiobjective Analysis

CRITERION 2. Availability of requisite data.

CRITERION 3. Appropriateness of objective(s) or system performance measure(s).

It will turn out that a critique of the five basic methodologies will require that most of the issues in Table 5-1 be discussed in one fashion or another.

In Section 5.2, it was seen that each evaluation method depended for its application on knowledge of attributes; some methods such as benefit-cost analysis and decision analysis utilized only a single attribute while other methods utilized multiple attributes. It is extremely important to understand that there are two general classes of attributes:

CLASS 1: Attributes pertaining to outcomes or consequences. For convenience, call these "status of forces variables".

CLASS 2: Attributes pertaining to the amounts of different types of information affecting outcomes. For convenience, call these "information variables".

Recall that both decision analysis and multiattribute analysis are concerned with consequences or outcomes; decision trees must be built which reflect whether certain purge procedures are in effect. Different outcomes will generally be realized according to which purge procedure is operative; it is the expected utility of these outcomes that both decision analysis and multiattribute analysis regard as a measure of performance of a purge procedure. In a military context, such "outcome utilities" will be functionally dependent on variables describing the status of forces.

The situation is somewhat different with benefit-cost, cost-effectiveness and multiobjective analysis. In any of these methods, benefits or utilities, as is appropriate, may be couched in terms of either status of forces variables or in terms of information variables.

Construction and implementation of a purge algorithm requires that one be able to determine what pieces of information are essential. As will be seen in the next section, this determination requires an empirical study of each military command environment for which a purge algorithm is considered. Because this empirical study will define CLASS 2 attributes, i.e., information variables, it will be seen that a certain economy may exist in using CLASS 2 attributes for benefit and utility specification.

5.3.1 CRITERION 1: Essential Information

Because of its central importance, it is useful to outline a general approach to defining essential information. Essential information is ultimately a subjective concept and must be defined in light of each individual decisionmaker's experiences and approach to problem-solving. That is to say it is entirely possible that for a particular purge situation each decisionmaker will possess a distinct view of what pieces of information are essential. On the other hand, it may be possible that groups of like-minded decisionmakers may exist who are in consensus as to what are the essential pieces of information in a given situation.

What is required is an empirical measurement of the attitudes of decisionmakers toward each particular military situation in which purge alternatives might be applied. This measurement is schematically portrayed in Figure 5-4. The experimental approach depicted in Figure 5-4 is essentially one of exposing an appropriate group of decisionmakers to a set of scenarios typifying the military environment of interest. For each of these scenarios, individual decisionmakers will note what types of information are preferable, and rank order those types of information. One then looks to see if overall or subgroup consensus exists regarding the essential types of information. Clearly, this last determination requires statistical analysis be performed; linear discriminant analysis would be most appropriate in this situation.

A second statistical analysis is indicated in Figure 5-4 by the dotted arrow and boxes. The point of this analysis is that at the same time one is seeking information regarding the rank orderings of different pieces of information, one may also request the experimental population to provide subjective scores (on say a scale of 1 to 10) of the different information bundles which would be presented. These subjective scores together with the known values of the information variables may be used in a regression analysis to determine the utility of the entire experimental population, its subgroups or of individuals as a function of the information variables. That is, such an analysis would develop explicit mathematical statements of the perceived utility of having given amounts of each piece of essential information.

Given the general approach to defining essential information and information dependent utilities described above, it is now appropriate to consider the compatibility of each of the five basic evaluation methodologies with that approach. Table 5-3 presents a summary of the primary issues associated with this question of compatibility.

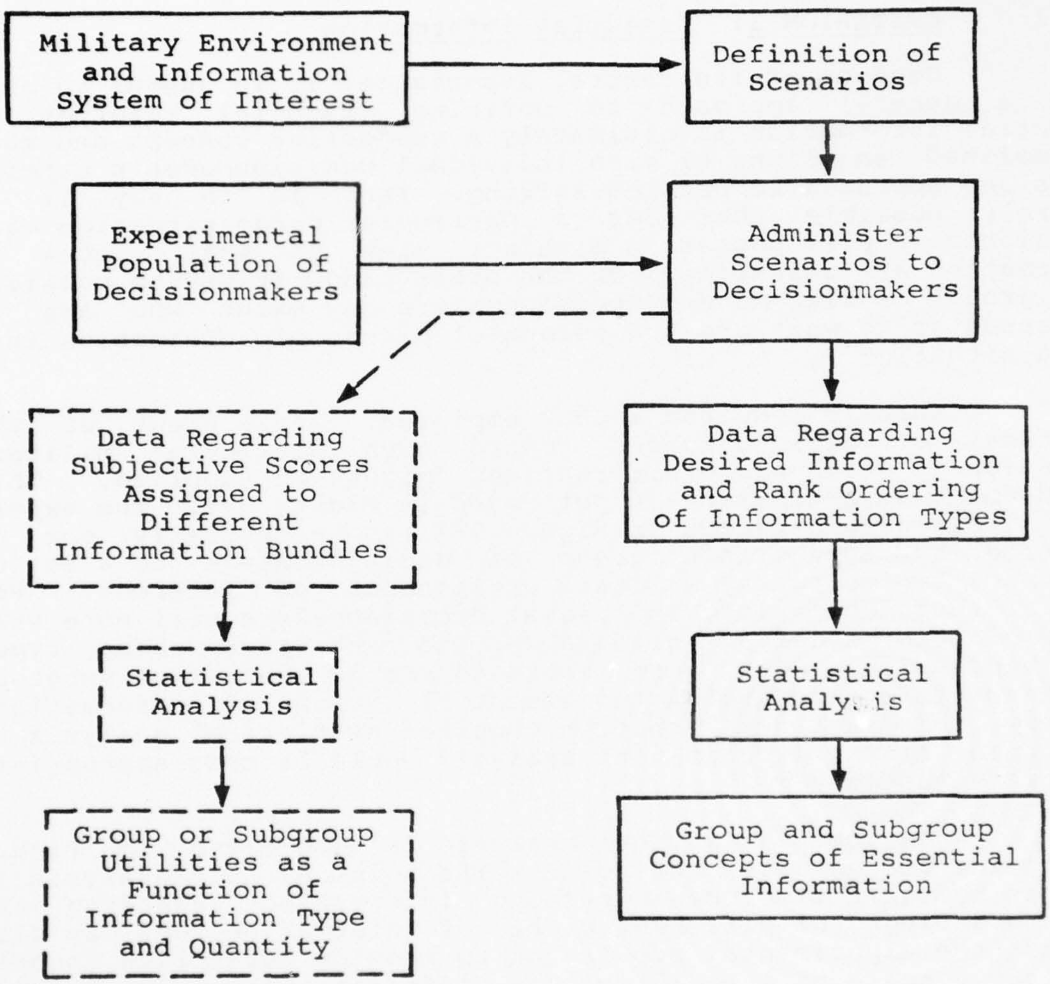

Figure 5-4. Empirical Approach to Defining Essential Information

Type of Evaluation Method	Uses Essential Information in Benefit/Utility Expression	Require Status of Forces Utility Expression	Compatible with Conflict Among Decisionmakers Concerning Definition of Essential Information
1 (Benefit-Cost Analysis)	Yes*	No*	No
2 (Cost-Effectiveness Analysis)	Yes	No	No
3 (Decision Analysis)	No	Yes	No
4 (Multiattribute Analysis)	No	Yes	No
5 (Multiobjective Analysis)	Yes	No	Yes

Table 5-3. Results of Applying Criterion 1 (Essential Information) to the Five Basic Evaluation Methodologies

* These answers hold only if essential information prices are estimated without resort to status of forces variables. See Section 5.3.2.1 for details.

Before discussing how the findings on Table 5-3 were reached, it is necessary to discuss the meaning of each column entry. If an evaluation method may make direct use of results from the empirical assessment of essential information, then "yes" would appear in the first column; a yes-answer is regarded as an asset for it indicates that the basic empirical work necessary to design and implement a purge algorithm may also be used for its evaluation. Those types of methods with a yes-answer in the first column will have a no-answer in the second column and conversely. This is simply due to the fact that if information variables cannot be used in evaluation, then status-of-forces variables must be used; if this latter type of variable is used, then a second empirical study must be conducted to determine decisionmaker utility as a function of outcomes. Thus, a no-answer in the second column is considered an asset. Because it is entirely possible that decisionmakers will not agree as to what pieces of information are essential, it is also an asset to have a yes-answer in the third column.

To understand the findings of the first and second columns of Table 5-3, first consider the simplest evaluation method, benefit-cost analysis. This method may be applied to the evaluation of purge innovations as follows:

> The presence of essential information would be regarded as a benefit; the amount of each essential piece of information would be valued in terms of some common numeraire (probably dollars). The presence of non-essential information would be regarded as a "disbenefit" or cost; the amount of each non-essential piece of information would be valued in terms of the common numeraire. The benefits and costs described above, along with any capital, operating, maintenance or replacement costs, would be used in conjunction with the investment criteria of Table 5-2 for the evaluation of each innovation of concern.

Given the above paradigm the entries in columns one and two of Table 5-3 opposite benefit-cost analysis become clear: if this paradigm is followed it would seem, at least on the face of things, that one may avoid the use and measurement of status-of-force variables. Thus, the empirical assessment necessary to establish essential information seemingly will also suffice for the conduct of benefit-cost analysis. Extension of the benefit-cost analysis paradigm to the methods of cost-effectiveness analysis and multiobjective analysis is straightforward.

To perform cost-effectiveness analysis one uses an information variable-dependent utility expression from the empirical procedure outlined in Figure 5-4 in conjunction with the mathematical formalism described in Section 5.2.2. Costs for this method of analysis are confined strictly to capital, operating, maintenance and replacement costs. Thus, cost-effectiveness analysis receives a yes-answer in column one and a no-answer in column two of Table 5-3, because it may be performed entirely in terms of information variables.

The multiple utility expressions describing individual or group preferences which are required as input to multiobjective analysis also come from the empirical procedure outlined in Figure 5-4. These utility functions are, of course, in terms of information variables, and are used in conjunction with the analysis procedures described in Section 5.2.5 and Appendix D. Thus, multiobjective analysis receives a yes-answer in column one and no-answer in column two of Table 5-3, because it too may be performed solely in terms of information variables.

Decision analysis and multiattribute analysis, as has already been pointed out, both require the use of status-of-force variables. The entries in Table 5-3 opposite these two evaluation methods reflect this fact.

The findings of the third column of Table 5-3 stem from the fact that regardless of whether utilities and benefits are measured in terms of CLASS 1 or CLASS 2 variables, if more than one group exists with respect to the definition of essential information, ambiguity arises in TYPE 1 through 4 methods. This is best understood by referring to the conceptual purge model described in Figure 5-1. There it is seen that if consensus does not exist regarding what pieces of information are essential then distinct purge algorithms would be implemented depending on which group's point of view was considered. This would lead to distinct versions of the data base and possibly to distinct actions on the part of the decisionmaker(s). If the evaluation is couched in terms of information variables, distinct data bases would lead to distinct benefits/utilities for each group. Thus, no matter which of the TYPE 1 through 4 methods are used, different values for each method's performance measure may be expected for each conflicting group of decisionmakers.

Only TYPE 5 (multiobjective analysis) methods avoid the dilemma just cited. This is because TYPE 5 methods may accommodate many distinct and conflicting groups. In fact, TYPE 5 may accommodate the extreme case of all decisionmakers involved possessing different definitions of essential information. Consequently, in the third column of Table 5-3 only TYPE 5 receives a yes-answer.

5.3.2 Criterion 2: Availability of Requisite Data

In all of the evaluation methodologies discussed, the primary type of data which must be available in all cases is data concerning the attributes utilized in evaluation. The single attribute evaluation methodologies require that each of the dimensions of information or outcome (depending on whether CLASS 1 or CLASS 2 attributes are used) must be expressible in terms of a common numeraire; in effect, one must know "prices" by which the attributes may be multiplied in order to reduce all the attributes to the common unit of dollars. Thus, there are really two questions of data availiability:

- What are the amounts of the attributes of a given military/information system environment?
- What is the price or per unit value of each attribute?

Clearly the second question is only posed for cases where utility is expressed as net monetary value.

5.3.2.1 TYPE 1 Methods: Benefit-Cost Analysis

To understand these issues better, consider the simplest evaluation method: benefit-cost analysis. Assume attributes are CLASS 2, i.e., the problem is couched in terms of information variables. Then the net benefits associated with a type of essential information i at a time t are given by:

$$B_{it} = \sum_{j=1}^{4} \left(P_{ijt} I_{ijt} - C_{ijt} \right), \qquad (6)$$

where

I_{ijt} = amount of the i^{th} type of information subjected to the j^{th} data manipulation at time t.

P_{ijt} = "price" of performing the j^{th} data manipulation per unit of the i^{th} type of information at time t.

j = data manipulation index = 1 if purging occurs
2 if post purge retriveal occurs
3 if storage occurs
4 if information not available

C_{ijt} = capital, operating, maintenance and replacement costs for data management involving the j^{th} form of data manipulation of the i^{th} type of information at time t.

It is important to note that the P_{ijt} may be either positive or negative depending on whether I_{ijt} is a benefit or disbenefit (cost). Total net benefits for the time t are then obviously given by:

$$B_t = \sum_{i=1}^{M} B_{it}, \tag{7}$$

where M denotes the number of types of information considered. The present value of benefits is then calculated by analog with Table 5-2 from the formula:

$$\text{Present Value of Net Benefits} = \sum_{t=1}^{T} \frac{B_t}{(1+i)^t}, \tag{8}$$

where T is the "planning horizon" or total number of time increments considered and i is the appropriate discount rate. The present value of net benefits (8) is calculated for each purge alternative. The alternative with the highest positive value is the optimal one.

Expressions (6), (7), and (8) were developed to make explicit the data requirements of a TYPE 1 evaluation methodology. Inspection of these relationships reveals that the most basic data needed are the P_{ijt} and the I_{ijt}. How can this data be obtained? Consider the information variables I_{ijt} first; these are obtained directly from the purge algorithm itself. That is, if one were to apply a purge algorithm to a given data base in a given military environment, the variables I_{ijt} would be obtained. Thus, the I_{ijt} could be obtained either from historical data or a simulation model. A simulation model for this situation would be relatively easy to construct: essentially a data file of time dependent sensor readings would be input to the purge algorithm, which would then output values for the information variables I_{ijt}.

Determination of the prices P_{ijt} is a more difficult matter. This determination like that for the information variables will also require either historical data or a simulation model. The associated simulation model would, however, be considerably more complex. To see this, consider the conceptual model of purge operations, Figure 5-1. This figure shows clearly that the required simulation model would contain the elements mentioned above for setting numerical values for the I_{ijt}, but it would also contain a module to describe the decisionmaker's reaction to the data base constructed by the purge algorithm. This reaction would comprise a set of military actions and associated battle outcomes. By holding all information variables I_{ijt}, except one, constant and observing changes in battle outcomes as the one non-constant information variable is allowed to change, it would be possible to observe the change in outcome (status-of-forces) variables per unit change of the non-constant information variable. Insofar as each set of outcome (status-of-forces) variables represents a set of dollar costs or benefits incurred, one may then calculate the dollar costs or benefits associated with a unit change in any information variable; these are just the prices P_{ijt}[10] that are desired.

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[10] Note that the P_{ijt} are therefore exactly the "costs" of purging, regaining information, storage and not having information. The term "costs" is placed in quotations to emphasize that some of these "costs" may actually be benefits. The simulation procedure described constitutes a systematic method for obtaining these "costs". If a detailed simulation procedure like that suggested cannot be constructed, for whatever reasons, one may resort to less sophisticated, non-computer procedures which will all be characterized by severe assumptions regarding to decisionmaker's reaction to the data base as modified by the purge algorithm. These assumptions are necessary to reduce the problem to one which the analyst, unaided by the computer, can deal with. Only a computer simulation is apt to be able to treat the myriad of complex interactions among decisionmaker, data base and outcomes.

There is a very serious drawback to the previously outlined procedure for estimating information prices, a drawback which serves to strongly motivate and recommend cost-effectiveness analysis. The drawback is that in order to determine information prices it is necessary to perform a simulation which ultimately leads to outcomes articulated in terms of the CLASS 1 attributes, i.e., in terms of status-of-forces variables. (It is this fact which accounts for the caveat, expressed as a footnote, of Table 5-3.) This begs the question of why bother to formulate the problem in terms of CLASS 1 attributes, i.e., information variables, in the first place. There is no satisfactory rebuttal; the evaluation could have been conducted in terms of the status-of-forces variables from the outset. In that case, the net benefits at time t would be simply:

$$B_t = \sum_{i=1}^{R} P^E_{it} E_i - \sum_{j=1}^{S} P^F_{jt} F_j, \tag{9}$$

where

E_i = Amount of the i^{th} class of enemy personnel or material destroyed;

F_j = Amount of the i^{th} class of friendly personnel or material destroyed;

P^E_{it} = Price of one unit of the i^{th} class of enemy personnel or material at time t;

P^F_{jt} = Price of one unit of the j^{th} class of friendly personnel on material at time t.

R = Number of classes of enemy personnel or material considered.

S = Number of classes of friendly personnel or material considered.

The present value of net benefits are then calculated as before according to equation (8). Note that the issue of estimating information prices does not exist in formulation (8). One is faced with finding men and material prices, something which is commonly done in military cost analysis. It is important not to forget that formulation (8) still depends on the existence of a complex simulation model or extensive historical data which can describe what the outcomes, measured in status-of-forces variables, will be for a given purge system. This last requirement is still a severe one.

5.3.2.2 TYPE 2 Methods: Cost-Effectiveness Analysis

Cost-effectiveness analysis has a very significant advantage over benefit-cost analysis (whether in terms of CLASS 1 or CLASS 2 attributes). That advantage is that if cost-effectiveness analysis is conducted in terms of CLASS 2 attributes (information variables) a complex simulation relating purging to battle outcomes is avoided; it is avoided by the introduction of the multiattribute utility function expressed in terms of the information variables I_{ijt} introduced in the previous section. This means that one needs only conduct a simple simulation based on the purge algorithm itself. This simulation is illustrated by the flow diagram of Figure 5-5. The cost-effectiveness criterion, equation (4) of Section 5.2.2, is applied to select the optimal purge alternative.

5.3.2.3 TYPE 3 and 4 Methods: Decision Analysis and Multiattribute Analysis

Decision analysis and multiattribute analysis both require the construction of decision trees for their implementation (see Sections 5.2.3 and 5.2.4). These decision trees will necessarily be very complex and very tedious to construct for a modern complex military environment. For any given situation with which a decisionmaker is faced, there are at least three alternatives; each act of selecting from among these alternatives must appear as a decision node in the decision tree. The three alternatives are:

- Act;
- Don't Act;
- Get More Data.

Each time the third decision, get more data, is made, the decisionmaker must then face the same three decisions again at the next point in time for which a decision must be made. As time passes, the information data base changes, both as a result of new sensor readings and as a result of the particular purge algorithm. Thus, at each subsequent point in time the data available to the decisionmaker regarding his situation changes

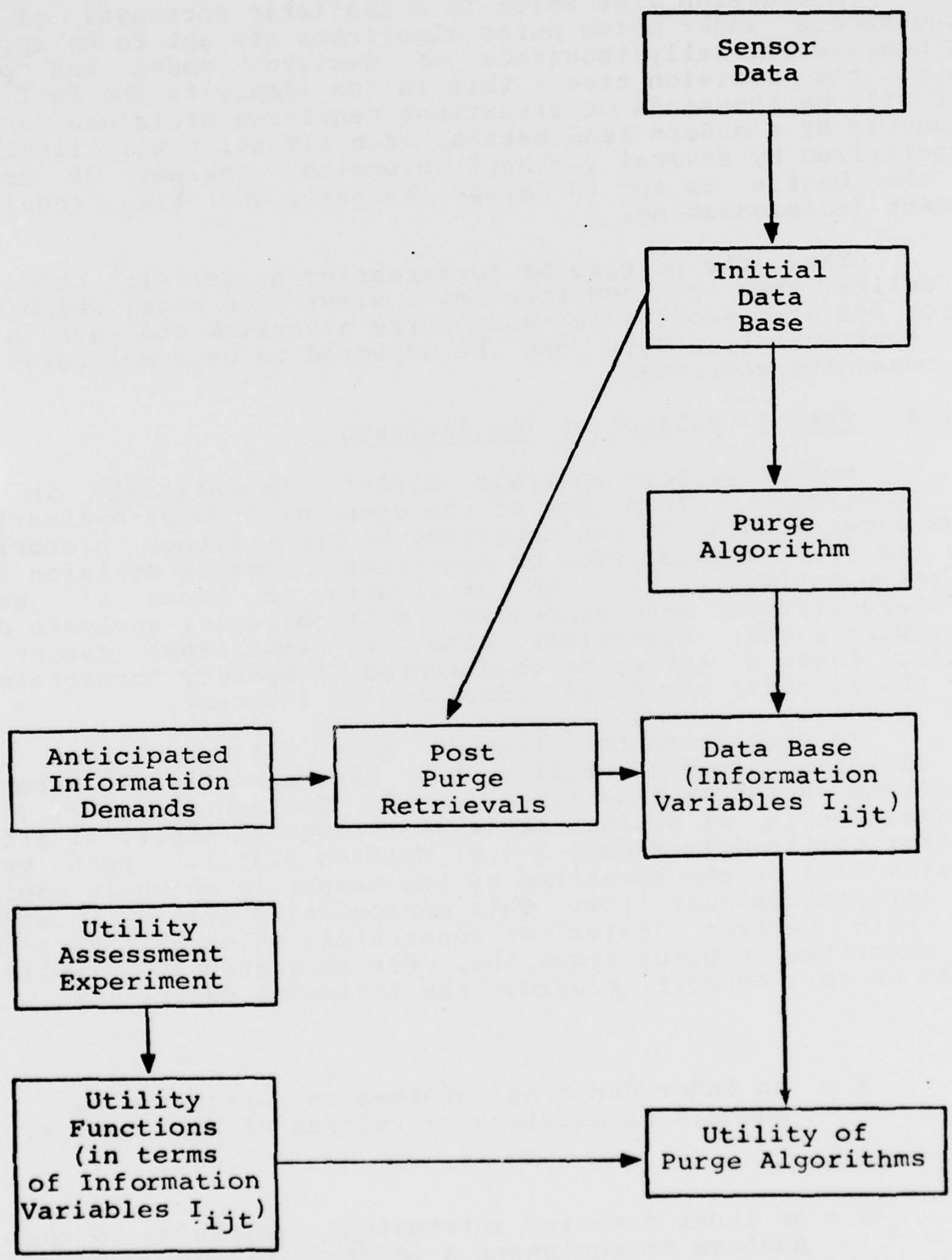

Figure 5-5. Simulation to Define Information Variables and Purge Algorithm Utility

and consequently so do the subjective probabilities assigned to estimate the likelihood of each outcome on each branch of the decision tree.

A decision tree which is a realistic portrayal of the circumstances under which purge algorithms are apt to be applied must contain literally thousands of decision nodes and paths through the decision tree. This is due simply to the fact that there will be thousands of situations requiring decisions during the course of a modern land battle, each situation will likely be characterized by several (perhaps dozens) of courses of action and the battle is apt to change character over time, requiring frequent decisionmaking.

Thus, the problem of constructing a decision tree is not unlike that of constructing a simulation model which will predict status-of-forces for each purge algorithm and each military environment. Both may be expected to be complicated and time consuming exercises.

5.3.2.4 TYPE 5: Multiobjective Analysis

Multiobjective analysis differs dramatically in its data requirements from any of the other methods of evaluation. In the other methods it was necessary to apply either historical data, perform a simulation or construct a complex decision tree to determine values of the attributes in terms of which benefits/utilities were expressed. Multiobjective analysis does not require either historical data or simulation; rather it requires that a survey be constructed to specify "constraints" which characterize the purge algorithms of interest.

To understand this feature more fully, suppose that each decision group's utility has been specified in terms of information variables like the I_{ijt} in Section 5.3.2.1 (this specification is, of course, achieved through an empirical effort like that outlined in Figure 5-4 of Section 5.3.1). Each purge algorithm will be characterized by the manner in which it manipulates information over time. This manipulation will be in accordance with certain "rules" or constraints which will vary from purge algorithm to purge algorithm. For an extremely simplified example of this concept, consider the following definitions:

ℓ = an index denoting information pertaining to numbers of maintenance records of equipment X.

m = an index denoting information pertaining to the numbers of equipment X in the division.

t = time index.

j = data manipulation index.

It will be recalled from Section 5.3.2.1 that $j=1$ if information is purged; $j=3$ if information is stored. Hence, if the purge algorithm specifies that maintenance records are to be purged in the time period following a zero level of the equipment to which those records refer, that rule or constraint may be expressed symbolically as:

$$I_{\ell,3,t+1} = I_{m,3,t} = I_{\ell,3,t} - I_{\ell,1,t}. \tag{10}$$

This simple statement merely requires that the number of maintenance records for pieces of equipment of type X equal the number of pieces of equipment which existed in the previous time period. Thus, if there were zero pieces of equipment at time t, the system would eliminate all maintenance records by time t+1. Similarly other rules describing a particular purge algorithm may be translated into constraints like (10).

Thus, if one uses the notation I to represent a vector of information variables like I_{ijt} and if there are N like-minded decisionmaking groups, then the appropriate multiobjective analysis is formulated as:

$$\text{Maximize} \left[U_1(I),\ U_2(I), \ldots . U_N(I)\right] \tag{11}$$

Subject to constraints involving I.

In (11), U_i represents the utility of information of the i^{th} group. Moreover, the information variables are treated as unknowns which are found by solving the optimization problem (11); hence, once does not conduct measurements or simulations to find their values as in the other methods, but rather a survey to determine information constraints imposed by the purge algorithm of interest when operating within a given decisionmaking environment. Section 5.4 describes the multiobjective analysis (11) in more detail.

5.3.3 Criterion 3: Appropriateness of Performance Measures

If consensus exists among decisionmakers any of the TYPE 1 through 4 evaluation methodologies may be used. As has already been pointed out, if there are multiple decisionmakers who are in conflict, only TYPE 5 (multiobjective analysis) procedures are appropriate. Whether such conflict exists can only be determined by an empirical study like that suggested in Section 5.3.1.

5.3.4 Summary of Critique

Section 5.3 has presented a variety of pro and con arguments concerning the the five basic evaluation methodologies. These are summarized in Table 5-4.

5.4 RECOMMENDATIONS

In Section 5.3 the five basic evaluation methodologies were described and critiqued. This critique found that each methodology suffered from certain drawbacks that were uniquely its own. Of the five basic methodologies, TYPE 5, Multiobjective Analysis, appears to be the most promising. It is the purpose of this section to succinctly describe how multiobjective analysis may be applied to the evaluation of purge procedures.

5.4.1 Requisite Data for Multiobjective Analysis

It is appropriate to begin with a rhetorical question: What information is necessary to perform a multiobjective analysis of purge procedures? One may point to four categories of requisite information:

1. The number of distinct, like-minded subgroups of decisionmakers in the decision environment where the purge algorithm of interest will operate.
2. Utility functions expressed in terms of information variables for each subgroup of like-minded decisionmakers.
3. Constraints involving the information variables which express the mechanics of the purge algorithm of interest as well as special features of the decision environment.
4. The relative "weights" of each group's utility.

The method for uncovering the information described in items 1 and 2 above has been presented in detail in Section 5.3.1. The information described in items 3 and 4 above may also be gathered during the empirical effort presented in Section 5.3.1. This may

Table 5-4. Summary of Evaluation Method Critique

Method Type	Criterion 1: Essential Information	Criterion 2: Data Requirements	Criterion 3: Performance Measures
Type 1 (Benefit-Cost Analysis)	Benefits may be articulated in terms of amounts of essential information.	Prices of attribures (status-of-forces or information variables) must be estimated. Amounts of attributes must also be estimated.	Single objective nature not compatible with multiple decisionmakers in conflict over what attributes are appropriate.
Type 2 (Cost-Effectiveness Analysis)	Amounts of essential information may be used as attributes in group utility function.	Not necessary to estimate prices. Amounts of attributes must still be estimated.	Same as above.
Type 3 (Decision Analysis)	Requires status-of-forces variables as attributes; these will not directly result from empirical determination of essential information.	Complex decision tree with estimates of outcomes and subjective probabilities required. Must obtain prices of attributes to reduce problem to one attribute.	Same as above.
Type 4 (Multi-attribute Analysis)	Same as above.	Complex decision tree and associated data as in Type 3. Prices of attributes not necessary.	Same as above.
Type 5 (Multi-objective Analysis)	Amounts of essential information may be used as attributes in subgroup utility functions.	Construction of constraint set to describe purge algorithm.	Compatible with as many distinct utilities as there are decisionmakers but may be computationally difficult if non-linearities occur.

be seen by referring to Figure 5-6 which is essentially an expanded version of Figure 5-4.

In Figure 5-6 it is seen that by addressing appropriate questions to the experimental population and by confronting that population with appropriate scenarios it is possible to extract not only the information described in Figure 5-4, but certain additional information as well. That additional information includes the relative importance of each command level in terms of influencing outcomes within the environment of interest. Such measures of relative importance are actually numerical indices or "weights" which describe the rank order of the subgroup utilities. These weights play a key role which is described in detail in 5.4.2.

A second type of additional information determined from the empirical approach of Figure 5-6 is a set of constraints on information flow for the environment of interest and for each purge algorithm operating in that environment. These constraints on information flow may be purely of a mechanical or technological variety, as was discussed is section 5.3.2.4. The constraints may also be of an institutional or even psychological nature, involving either arbitrary operating policies on the one hand or human perceptions which function as bottlenecks in processing information on the other hand.

5.4.2 Example Formulation of the Multiobjective Analysis Problem

For simplicity of exposition suppose that the empirical effort of Figure 5-6 has uncovered two distinct subgroups of decisionmakers within the environment of interest. Suppose the empirical effort has also uncovered two distinct types of information which are valued (differently by each subgroup) in making decisions. The subgroups are found to be characterized by utility functions of the form.

$$\left.\begin{aligned} U_1 &= f_1(x_1, x_2) \\ U_2 &= f_2(x_1, x_2), \end{aligned}\right\} \quad (12)$$

where x_1 and x_2 represent the two types of information used in decisionmaking. It is important to realize that in (12) the functional forms of the utilities are actually known through previously conducted statistical inference.

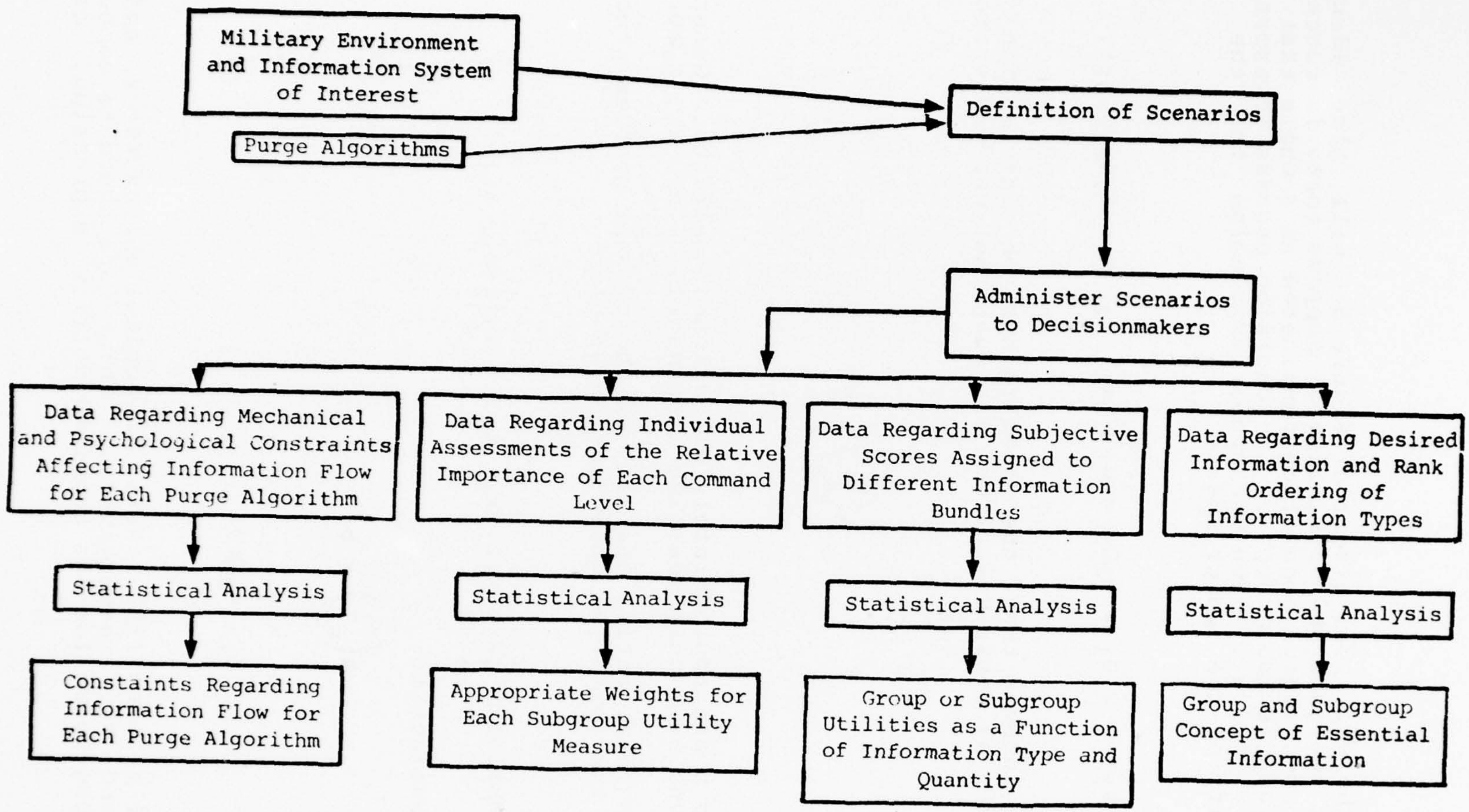

Figure 5-6. Empirical Approach to Obtaining Information Necessary to Conduct of a Multiobjective Analysis

The empirical effort of Figure 5-6 will also identify appropriate weights and constraints. Suppose there is concensus among the experimental population considered as a whole that the importance of the two groups in the decision process is expressed by weights w_1 and w_2. Then the proper expression for the combined utility of the two groups is

$$U(x_1, x_2) = w_1U_1 + w_2U_2 = w_1f_1(x_1, x_2) + w_2f_2(x_1, x_2). \quad (13)$$

Furthermore, assume that the constraints on information flow uncovered in the empirical effort are such that one may write

$$A\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = b \quad (14)$$

where A and b are appropriately dimensioned matrices. Generally one also considers only positive information, i.e., $x_1, x_2 \geq 0$.

Multiobjective analysis of the present problem proceeds by solving the following optimization problem:

$$\left.\begin{array}{l} \text{MAXIMIZE } \left[U = w_1f_1(x_1, x_2) + w_2f_2(x_1, x_2)\right] \\ \text{Subject to} \\ \qquad A\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = b \\ \qquad x_1, x_2 \geq 0. \end{array}\right\} \quad (15)$$

Solution of problem (15) results in optimal values for x_1 and x_2; say x_1^*. and x_2^* respectively. These are used to compute a correspondong value for the combined utility expression, called U^* where

$$U^* = U(x_1^*, x_2^*). \tag{16}$$

Each purge algorithm will generally correspond to a different value of U^*. The purge algorithm with the highest value of U^* is considered the "best". The solution of problem (15) is accomplished by applying the techniques of mathematical programming; if the functions $f_1(\cdot)$ and $f_2(\cdot)$ are linear, one may utilize linear programming.

In the approach described above certain complications may arise. First recall that equations (12), (13) and (14) are determined through procedures which involve statistical inference. This means that result (16) has a confidence interval associated with it, i.e., a least value and a greatest value with a certain reliability of lying between those extremes. Therefore, it may happen that the U^* values for different purge algorithms will have overlapping confidence intervals. In this case the purge algorithms involved may not be distinguisable, i.e., no one of them is "best". Note that this overlapping of performance measures could happen with any of the evaluation methodologies considered earlier and is not a phenomenon inherent to multiobjective analysis.

A second complication arises when there is not group consensus regarding the numerical values for the weights w_1 and w_2 used in equation (13). In this instance one cannot generate a unique performance score but only a trade-off curve for the two utilities U_1 and U_2, as depicted in Figure 5-7.[11] Different trade-off curves will then be generated for different purge algorithms.

In some cases it will be possible to select the "best" purge algorithm by comparing trade-off curves. Such a circumstance is illustrated in Figure 5-8. In this figure it is seen that algorithm A everywhere delivers greater utility to both groups of decisionmakers than does algorithm B; hence A is clearly the better algorithm. However, in Figure 5-9 it is seen that without additional information algorithm A cannot be said to be better or worse than algorithm B; the two algorithms are not distinguisable.

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[11] See Appendix D for a discussion of methods for generating trade-off curves.

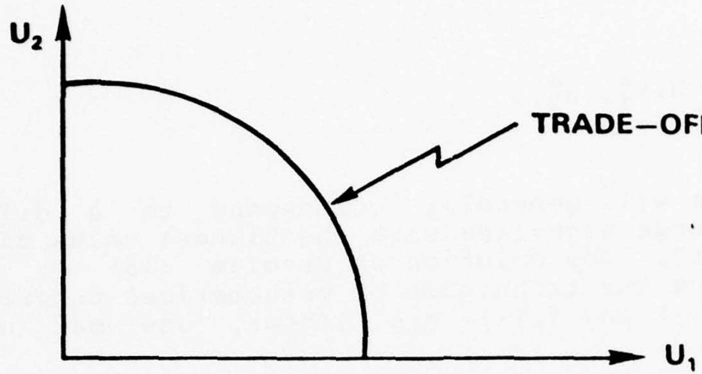

Figure 5—7. Two Utility Trade-Off Curve

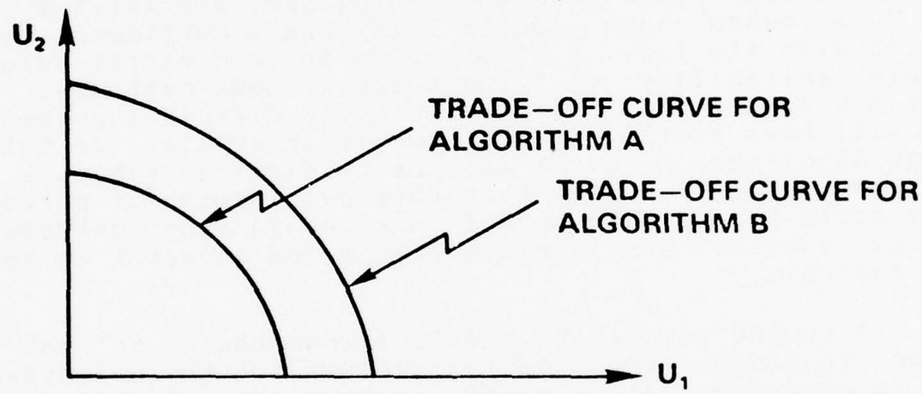

Figure 5—8. Comparable Trade-Off Curves

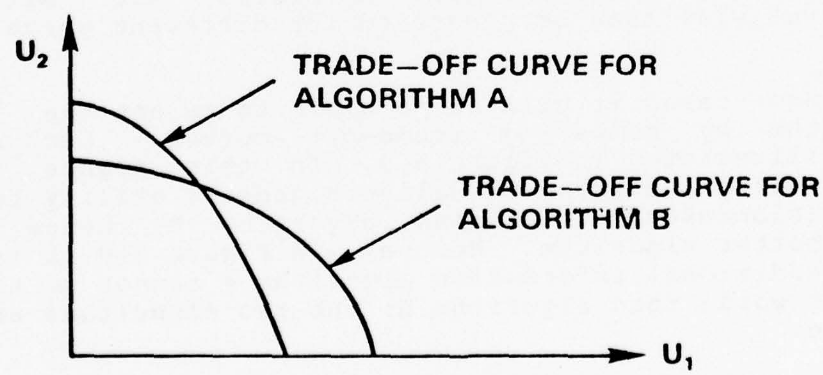

Figure 5—9. Non-Comparable Trade-Off Curves

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 PURGING STATE-OF-THE-ART

[illegible]eral, the technique of "purging" or disposing of infor[illegible]ich is no longer needed or has no further value is widesp[illegible] manual files or typed or written records are utilized [illegible]aintained. Normally, retirement of such records is accomplished at set intervals on a periodic basis. However, few of the individuals who accomplish or are associated with this process of retiring printed records or informational material view the procedure as one which is also applicable to automated information holdings. Nonetheless, the idea -- that of disposing of information no longer needed -- can and should be employed to assist in managing data processing files that are growing rapidly or are extremely dynamic. The computer industry, interested primarily in selling more hardware rather than with reducing a customer's demand for either main or secondary computer memory, has largely ignored the issue of purging.

The majority of U.S. command and control centers that exist for the direction of military forces or for crisis management presently maintain large automated data holdings. For the most part, these holdings deal with comparatively well delimited information sets that are updated periodically. At such times new information supplants old and old data is destroyed, though normally this data is held on tape for a given period of time -- usually until the file has been updated at least twice. Sensor data is available to warn of possible enemy missile or aircraft attack upon Continental United States, however, this dynamic data is normally not stored but utilized instantaneously, and then supplanted as quickly as new data is received. Message traffic and general information received during crisis situations can and frequently is automated and stored in ADP systems for ready reference. When the crisis has passed, such holdings are normally either placed on secondary storage medium (tape) for future reference as required or destroyed. In most cases, the computers utilized in these centers are very large and total saturation of the systems rarely occurs. Such will, of course, not be true for the small Tactical Operating System envisioned for use with Army Divisions in the field.

6.2 INFORMATIONAL NEEDS FOR COMBAT DIRECTION

Technology has given the military commander the ability to acquire more factual information regarding his adversaries disposition and activity than ever before. This, in turn, has stimulated growing appetites for even more information. Taken together, this information supply and the growing demand for more data make information management at Division level and above extremely difficult. Given current doctrinal precepts followed by the U.S. Army, comparatively finite sets of desired information can be identified for some functional purposes. Cursory analysis is contained in Chapter 4. Once decisions have been made regarding what information is most sought, purging mechanisms can readily be adapted to dispose of information or data that is no longer needed or desired. The process is not simple, however, and deserves further study to develop suitable purging algorithms that will fully satisfy a broad spectrum of individual commanders.

6.3 PURGING EVALUATIVE METHODS

A number of quantitative methods exist which can be utilized to evaluate purge technology innovations. All methods discussed in the paper have both advantages and disadvantages. Of those examined, Multiobjective Analysis appears the most promising. A description of how such a method might be applied is contained in Section 5.4.

6.4 RECOMMENDATIONS FOR FUTURE RESEARCH

This monograph represents but one facet of the information management problems associated with command and control of U.S. ground forces. Focus is centered primarily upon the handling of information received and stored in textual format. Little attention was devoted to the consolidation or fusion of information from diverse or multiple sources or to the automatic combination of information relating to activity or force disposition with geographic data in map or pictorial form. If the problem of information overload is as pressing as most observers believe, new innovative methods should be developed for display of stored information to improve comprehension and assimilation. This seems to offer the greatest payoff in terms of improved combat effectiveness through more effective command and control. Finally, the theoretical evaluative method developed in the paper should be tested for validity under appropriate conditions.

APPENDIX A

COMPUTER SUPPORT OF PURGING INFORMATION AND DATA BASES

In this study, the term purging is used in a broad context meaning the reduction of the amount of data or information that is stored anywhere in an information system including on main and secondary computer memory. The process is not limited to the removal of data or information already resident on computer memory but also extends to the screening and reduction of data before entry into the system. This approach permits the investigators to explore a large number of methods to prevent information, system, storage and communication overloads.

Once information and data requirements for a decisionmaker/analyst have been identified, then the task of determining alternative manual and automated methods for processing this data falls to the information scientist. Of principal concern with an automated system is the amount and type of computer memory required. The limited capacities of computer memory hierarchy must be managed in a way that will save memory space and at the same time support information requirements in as responsive a manner as possible. One approach to accurate determination of these automatic data processing requirements is to examine each processing step for the system under consideration. These steps are defined as:

- Data Capture -- the initial acquisition of the data for computer processing;

- Screening -- the manual, semi-automated or automated means to determine what data or reports will be processed on the computer, where in the hierarchy of memory devices data will initially reside and how long its expected useful life will be;

- Pre-processing -- the techniques such as compaction or compression which will reduce the amount of computer memory required to store computer information; and

- Storage -- the actual process of storing and managing data in computer memory. This is a dynamic process which will establish initial storage assignments, migrate or trickle data to lower hierarchical storage levels, perculate this data back to main memory and cause obsolete data no longer required to be destroyed.

To present a comprehensive picture of purging techniques available to a data processing manager, each of these steps in the process are discussed more fully below along with associated methods for reducing or managing data within computer memory.

DATA CAPTURE

At time of capture, data in the C^3 environment comes from a variety of sources. The data can be in the form of hard copy messages, telemetry signals from various sensor devices, telephonic or voice radio reports to command centers, and computer readable information from other computer systems in such form as decks of punched cards, and signals from computer networks. In the future, voice and handwritten information may even be capable of direct input into automated systems.

In the capture of sensor telemetry data, analogs exist for digital conversion and to correlate and summarize readings into intelligible reports. If this processing can be performed off-line from the main computer,then processed, summarized and placed in memory buffer, data can be made available on-call to the main computer. Depending on the level of sophistication of such off-line processing, it is possible to eliminate much duplication and redundancy in these sensor reports. This can have an immediate and dramatic impact on the amount of memory required in the primary computer system to support the function. In particular, such off-line processing can tend to offset the surge effect experienced when enemy activity impacts on a number of sensor systems simultaneously.

In most cases, hard copy, including handwritten messages, must be converted to machine readable form prior to insertion into computer memory. This may involve transfer of data from hard copy to hollerith cards, or conversion by key to tape or disc. The message length and ultimately the computer storage requirements, are largely a function of the verbosity of the message originator. This use of a limited, standard message vocabulary with selective application of standard abbreviations can reduce data storage requirements significantly. For example, describing three tanks or three enemy tanks requires 80 and 120 bits respectively with third generation computers. If one abbreviates the words to 3TK or 3ETK storage requirement can be reduced to 24 and 32 bits. This represents a storage reduction of 30% for the expression three tanks and 27% in expression three enemy tanks. Such savings can be generated by establishing standard conventions for data elements and military terminology, and through formatting messages in a standard manner. Costs associated with such an approach result from the expense of training and some loss of flexibility in message writing. Department of

Defense and Military Service representatives recognize this, and have made some progress in the standardization of military terminology and message formats.[1,2,3] However, to obtain the full benefit from such standardization much more rigid enforcement of these conventions is required.

Telephone or voice radio reports must either be reduced to a hardcopy document after receipt or entered on a computer data entry device before transmission. In both cases, a need exists for a specialized intermediary capable of introducing standard formatting and standard abbreviations. Intelligent terminals can provide operator assistance in the formatting and abbreviation of such telephonic messages.

Computer-to-computer communications will require extensive standardization of formats and terminology. This can be preplanned if the sending computer has a system software translation capability. Data compression and/or compaction techniques can also be used to reduce the time and cost of telecommunications in computer-to-computer transmissions.

SCREENING

Data screening can be accomplished when a determination is made concerning what C^3 related information will be processed manually and what will be processed on the computer. Cost-benefit considerations, timeliness of reports and report accuracy all are factors in this decision. Without deliberate study and requirement for strong justification it may be found over time that excessive and unnecessary amounts of information will be processed on a given computer. As information requirements change, determination of how the information or data will be processed must repeatedly be subjected to the same detailed scrutiny.

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[1] U. S. Department of Defense, Department of Defense Manual 5000.12M, Manual for Standard Data Elements , OASD-C, Washington, D.C., March 1970.

[2] U. S. Department of Defense, Department of Defense Dictionary of Military and Associated Terms , The Joint Military Terminology Group, The Joint Chiefs of Staff, Washington, D.C., September 1974.

[3] North Atlantic Treaty Organization, NATO Glossary of Terms and Definitions for Military Use. (AAP-6), NATO Standardization Agreement (STANAG) 3680.

Once determinations have been made as to how data will be processed, procedures can be established to screen incoming data from each source to determine, what category of processing it falls under. For example, some hard copy messages may be handled manually while information from others is processed on the computer. The screening process itself can be performed manually, semi-automatically, or automatically. With manual procedures an individual reviews incoming data and relegates it by category to the appropriate processing system. These categories can be broadly designated so that data involving nuclear weapons might be computer processed while data related to health and welfare would be processed manually. Finer screening can involve the immediate destruction of duplicate messages relating to purely administrative matters and the assignment of priorities for computer processing of messages involving data on nuclear targeting. Part of the manual screening process could involve the assignment of useful life codes to messages or data which will generate suspenses for future purge action.

Semi-automated screening procedures involve applications or system software to assist the operator in the screening process. A system can be programmed to identify key words such as nuclear, attack, enemy or penetration. Messages containing these key words can then be automatically flagged for detailed screening by designated persons.

One of the most important tasks in the screening process involves separation of action messages from those that are strictly for information. A semi-automated system might be programmed to key on words such as "request" or "proceed" and automatically place these messages in the action message category. The remaining messages might well have to be screened manually to determine if they are action or information types. Such semi-automated procedures should significantly reduce the manual screening workload. In a semi-automated system, a determination could well be made to route all action messages to computer processing so that message status can be monitored through an automated reporting system. The current operational concept for TOS system will result in many, if not most, of the information messages to be processed on the computer.

Fully automated procedures can also be established to seek key words, message priorities, or other defined designators that might be defined to determine automatically if data should be processed manually or on the computer. In this case, however, the process will proceed without operator intervention with flagged messages automatically accepted by the system for computer processing, automatic distribution and main computer memory storage. If computer processed, then a determination can also be made as to the expected useful life of the data and where in the hierarchy of computer storage devices the data should be placed.

Initial screening represents a critical point in the processing of data if one is to avoid system or storage overload. It is at this sorting point that messages or data queue up during a crisis and redundant and irrelevant messages choke the system while the relevant, high priority messages wait their processing turn. During crisis or combat conditions, every effort must be made to screen data quickly and efficiently without degrading the information flow process.

PRE-PROCESSING

Once available memory devices have been filled with data, little can be done in real-time to create more storage capacity. Long-term solutions involve selective migration or destruction of data or the acquisition of additional memory modules for the computer. In the short-term, the system must make the best possible use of the available computer memory. It is possible, during the stage of internal computer data processing and prior to actually storing data, to take steps that can increase the available memory by factors of 60 to 80 percent.

Some pre-storage processing methods designed to conserve computer memory employ data compaction or compression procedures. Data compaction is closely related to the approach, discussed previously, in which abbreviations and codes are used to reduce the amount of space specific information will occupy in a message, communications device or in computer memory. Martin describes two methods for such compaction.[4] One is dependent on the content of data or the structure of records. The other involves techniques that they can be built into general purpose software, hardware, or microcode. In some instances it is possible to use both methods or techniques and realize even greater computer memory saving. Gottlieb, et. al. differentiate between these compaction and compression techniques.[5] The authors define the process as follows:

> Compaction the physical representation of the data while preserving a subset of the information deemed "relevant information".

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[4] Martin, James. Computer Data-Base Organization. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1975, pp. 433-448.

[5] Gottlieb, Doron, Hagerth, Steven A., Lehot, Phillipe G. H., and Rabinowitz, Henry S., A Classification of Compression Methods and Their Usefulness for a LargeData Processing Center , AFIPS Conference Proceedings, 1975 National Computer Conference, May 19-22, 1975. Anaheim, California, pp. 453.

Compression reversible.

The compaction technique not included in compression involves the elimination of information considered superfluous. In the command and control applications there appears to be opportunity to approach the problem from both aspects. Some files, such as intelligence files might be degraded by the attempt to store only "relevant" data. However, in the dynamic operations environment it should be possible to aggregate much of the data and eliminate sizable amounts of redundant or superfluous information.

Elimination of Redundant Data Items

The evolving data base management systems and their associated integrated files facilitate the reduction or elimination of duplicate data entries. Currently, these tools are restricted to use with medium or large computer configurations. However, it can be expected in the near future that there will be flexible data base management systems created for smaller computer configurations of a size applicable to the environment in which tactical data processing is conducted. For large, integrated computer systems with shared files, the elimination of redundant files and the associated data represent a significant method for reducing data storage requirements.

Compaction on Sorted Random Keys

Gottlieb, et. al. describe a front compression/rear compaction scheme based on a sequence of sorted keys.[6] In this system only those portions of keys are stored in computer memory which are:

- not identical to the previous key;
- necessary to make K unique; i.e., distinct from previous key and following key.

This technique will eliminate "front string" characters which are identical to the first change in characters. The "rear string" which is not needed to distinguish elements in the key from the previous and following key are also eliminated. The advantage of this approach is obvious when one considers sorting on employee number, proper name or even date.

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[6] Ibid., pp. 453-454.

Compression by Differencing

Gottlieb, et. al. also describe differencing techniques as those which "compare a current record to a pattern record and retain only the differences between them.[7] For example, information in the compressed record is equal to the information in the current record less the information already in the pattern record. In a listing of persons from the same city for example, the city, state and area code will only be written for the first record in the group. A flag will indicate that this information is repeated for a specific number of records. This procedure is a generalization of the method of compaction on selected random keys described previously. Gottlieb, et. al., see such differencing schemes as a method for reducing the overall amount of information in storage by not repeating those parts of the information in a record which are already present in another record.

Differencing is normally applied to sequential files, however, when used with a direct access file the first record of a block which can be directly accessed must be left intact with no compression. In addition, it should be noted that the decoding of compressed data is expensive. For example, if a record is to be read, every record preceding it has to be searched back to the first full (not compressed) record. The cost of insertions and deletions is even greater.

Conversion from Human to Compact Notation

Martin describes additional procedures for compressing conventional notations to a very brief notation.[8] For example, storing the date May 25, 1967 as 0002. Once such abbreviations are established, they can continue to support data compression as long as the algorithm is used in the computer memory.

Suppression of Repeated Characters and Elimination of Empty Space

These techniques are described by Martin[9] as the elimination of storage allocated to records with empty fields.[10] The algorithm simply ignores the field when there is a void in the data. In many records there are a number of successively repeated characters. In such instances it is possible to indicate the first one of the repeated characters and then the number of times the character is repeated. A character in third generation hardware normally requires eight bits for description. With this compaction technique, the first character is an identical

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[7] Ibid., pp. 454-455.
[8] Ibid.
[9] Martin, p. 434
[10] Ibid, p. 436

string is described with eight bits and the following six bits indicate the number of times it is repeated.

Substitution

Martin further indicates that 256 first names of persons can be coded on one eight bit byte. This would include almost all of the first names that are commonly used. In a continued discussion of name coding, Martin states that, "in the United States, 128 entries could include about 80% of all of the surnames and 256 entries more than 90%." Thus, 90% of all surnames can be encoded so that each name would occupy the computer storage normally associated with describing a single alphanumeric character. This substitution procedure can be taken a step further to encode standard English words and phrases. Should a standard DOD language of command and control be developed, such an approach could be even more fruitful in savings of computer memory space.

Statistical Encoding

Gottlieb, et. al. describe statistical encoding as, "...a transformation of the user's alphabet, converting each member of the alphabet into a code bit string whose length is inversely related to the frequency of the member in the text.[11] For example, if the letter "e" has the greatest occurrence in the text, it will have the shortest code which might be 0. If the letter "w" has the least occurrence, then its code might be something like 10111111110. Martin has demonstrated that this reduction may result in an average of 2.9 bits per character or more depending on the skewness of the distribution.[12] This should be compared to the eight bits per character of the standard code. Such coding was developed by Huffman and bears the name Huffman Code.[13]

> Huffman coding, based on statistical characteristics of a file, provides an easy and effective method of file compression without necessitating any inquiry into the semantics of file records. Thus, one package can be used on a wide variety of files to achieve compression without investment of large amounts of programmer's time to investigate particular files for their storage-wasteful properties.[14]

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[11] Gottlieb, p. 455.
[12] Martin, p. 446.
[13] Huffman, David A., A Method for the Construction of Minimum-Redundancy Codes , Proceedings of the I.R.E., September 1952.
[14] Gottlieb, p. 455.

Gottlieb found in testing a Huffman encoding package on a variety of large insurance files, that the porrest results encountered on an already compacted file was 50 percent compression. Huffman coding can be applied to variable length as well as fixed length records whereas differencing can only be applied to fixed length records. There are a number of techniques that are variations of Huffman coding; one, the Hu-Tucker Code, preserves alphabetic ordering.[15]

APPLICATION

A a number of software packages are available to perform compaction and compression processing. However, compaction can also be implemented using micro-programming and special hardware.[16] In the command and control environment of essentially standard systems, it would be possible to develop a data compaction - compression package to support each computer configuration.

CONCLUSIONS

A wide variety of techniques exist that can be applied to save computer memory. Considering the limited space for adding memory modules to tactical systems and the danger of system and storage overload for both the tactical and strategic systems, it seems obvious that these techniques should be pursued. In measuring effectiveness, it should be remembered that more than one technique for data compaction-compression can be used at one time. Martin obtained interesting measurements for character suppression and Huffman Code.[17] Three typical files for manufacturing application gave the following figures for possible size reductions:

Original File Size (Bytes)	Reduction Using Suppression of Repeated Characters (%)	Reduction Using Huffman Code (%)
300,000	54	82
3 million	34	46
19 million	64	83

Martin also indicates that these reductions would have been still greater if the repeated characters had been suppressed first and then Huffman Code used.

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[15] Ibid., p. 457
[16] Martin, p. 447.
[17] Ibid., p. 448

STORAGE

Availability of computer storage space represents the most critical element in determining whether or not system or storage overload will occur. Army systems will have established protocols for the acquisition of data from a variety of sources, for the processing of the information to be entered in computer memory and the storage and of this information. Once computer memory or storage space is saturated, there is no way to continue to process information unless additional memory units are made available or segments of existing memory are purged. During those conditions of peak activity most likely to cause the overload there will be no time to procure or acquire additional memory. The alternative of purging files requires detailed preplanning lest important data be lost at critical times. Thus, a system should have adequate memory capacity to insure that increased operational activity will not saturate it. Some excess capacity can be provided to insure an acceptable risk that the system will not be easily overloaded. However, along with providing some cushion of excess capacity, a data storage management system is required to maintain the data base below saturation level. Such will be needed for both the large computers supporting administration and logistics management and for those systems of much more limited size and memory capacities such as TOS.

Most computer data bases, those supporting batch operations as well as on-line real time systems, are designed with a storage hierarchy. This hierarchy may have two, three, or more levels. In general, there are usually two levels. These levels are the main or primary memory and secondary or auxillary memory. Main storage normally consists of magnetic core or metaloxide semi-conductor devices (perhaps in the future to be replaced by magnetic bubble memory).[18] Such devices are fast but relatively expensive. Secondary or auxillary memory is generally slower and less expensive, particularly as one goes to lower levels of the storage hierarchy. An access gap exists between main and secondary memory and another between secondary memory devices which may be off-line or dismounted from the disc or tape units. The relationship of these devices is illustrated in the following diagram:

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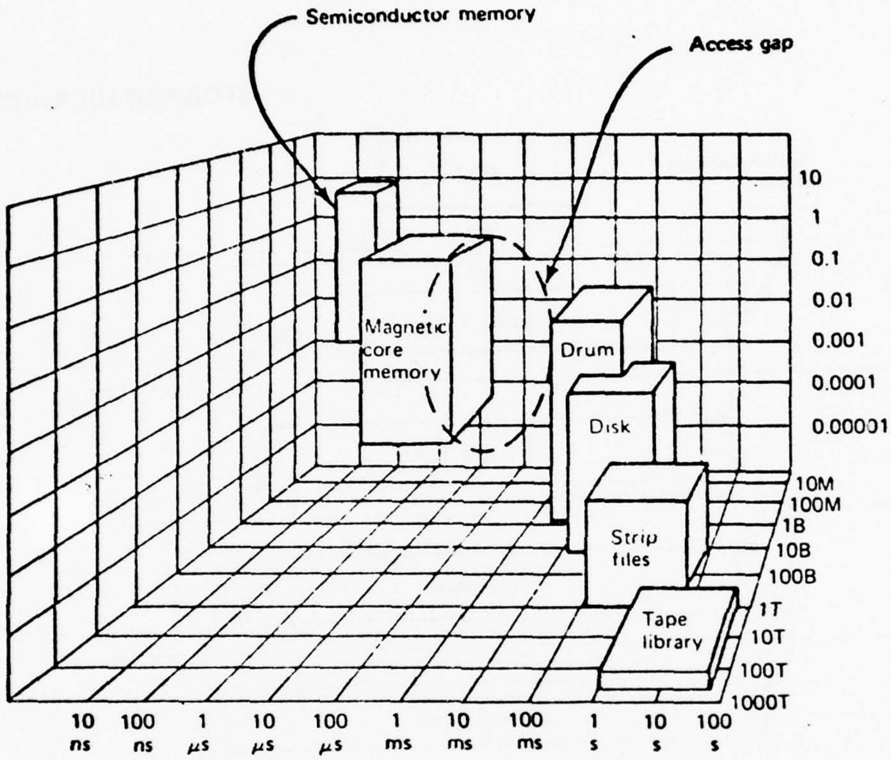
[18] Ralston, A. and Meek, C. L. Encyclopedia of Computer Science. New York: Petrucelli/Charter, 1976, pp. 1332-1359.

STORAGE HIERARCHY



Average Access Time

s second; T trillion; B billion; M million.

Storage Technologies[19]

In addition to a requirement for sufficient relative speed and the need to minimize cost, most Army tactical systems have severe space limitations which significantly influence the management of data storage. The hierarchical relationships of

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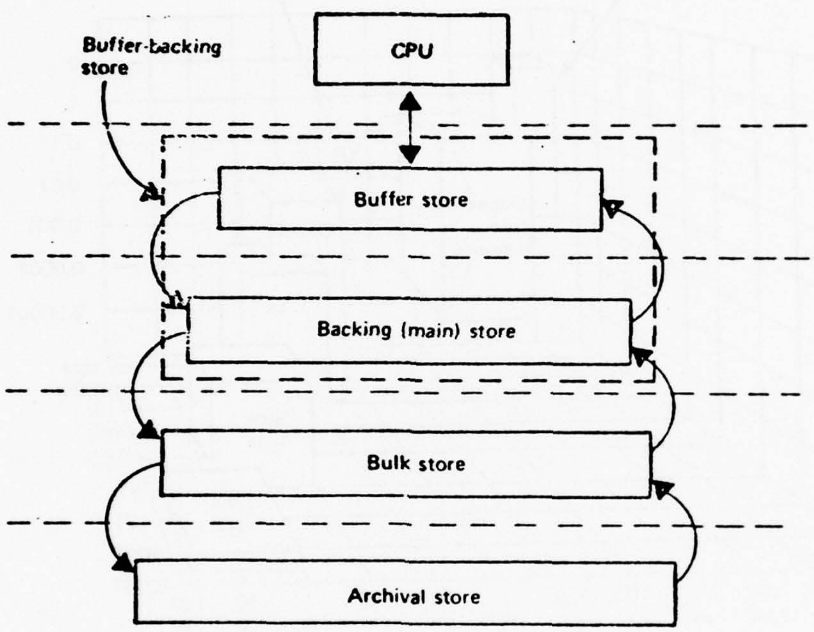
[19] Ibid., pp. 1337.

the computer storage systems are indicated in the next figure:

STORAGE HIERARCHY



Directly Coupled Hierarchical Storage System[20]

The degree of connectivity between hierarchical storage levels depends on the size and integration level of each specific system. Buffer store, sometimes called cache memory, and the main memory are the components of the central processing unit. Bulk store devices can be disc drives with permanent or removable disc packs, tape drives with removable reels of tape and drum or strip file devices. Archival store may or may not be on-line to the central processing unit. In a tactical environment this archival store may consist of reels of tape kept in tape libraries associated with Corps or Army headquarters and geographically removed from the originating computer system.

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[20] Ibid., pp. 1339.

Management of Data in Storage [21]

To focus on the problems of data management in storage, certain assumptions must be made. These are:

- data are screened and allocated to the hierarchical memory system by a predetermined algorithm;
- procedures are taken to minimize the amount of storage space the data will require, e.g., use of abbreviations or coding, data compaction or compression techniques;
- data are categorized according to its expected useful life and relative importance as a function of time;
- supporting data system will permit the transfer of data items, records and files from one storage device to another.

These assumptions provide the basis for designing a data storage system. The system can support the decisionmaker/analysts information requirements by providing him with immediate access to the most important information and a minimum delay in accessing the less important.

During the data capture function, data can be introduced to the computer in machine readable form, this data will be edited, compacted or compressed and then stored in main or one of the auxilliary memories. Ideally, the storage subsystems can be designed so that the storage structure is transparent to the user/programmer. Internal data transfer will be under the control of built-in algorithms.

The data storage algorithms can be designed so that data in main store is monitored for the decay in its relative importance. Once a threshold has been reached, then the data, file segment or file can either be migrated or "trickled" to a lower hierarchical memory level or erased. It is possible to accelerate or delay this process, depending on the data processing environment. Although in some systems it might be possible to establish fairly rigid rules for the migration of files, the dynamic nature of command and control data would almost preclude the establishment of a rigid system without some manual override provisions. This migration function can very well take place in archival store which may be remote from the computer system location.

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[21] Ibid., pp. 1332-1359.

Associated with the migration of files is the requirement for a system that will move data from lower levels of the storage hierarchy to higher levels or into the main memory. This procedure is sometimes called perculating. Timely responsiveness to a data query is, of course, a function of the hierarchical storage level. If in attempts to access specific data, system response is too slow or cannot access the necessary data, such can generate a signal for a process of perculation or upward migration of the files causing the delay. In the case of files that have been placed in remote archival storage, procedures can be established for retrieving data through a communications link or by other means such as a courier.

Criteria for moving files from one storage level to another is of utmost importance. Currently, such criteria is normally based on the last time a file was accessed. The dynamic and highly critical aspect of the data bases providing Army tactical information support require much more responsiveness and sophistication than this. Thus, new more effective policies and procedures must be established for efficient management of information residing in computer hierarchical data bases.

CONCLUSION

The ADP system supporting tactical operations must be able to respond to information requirements of Army decisionmakers with timely, accurate and pertinent information under all levels of crisis or combat operations. The procedures outlined in this Annex can contribute greatly to the success of the tactical ADP system in meeting these requirements.

APPENDIX B

ANNEX S (REPORTS) DIVISION TAC SOP

RPT NR	TITLE	FROM	TO	FREQUENCY	METHOD OF TRANSMISSION	REMARKS
1	Spot Report	Bde/Bn/Co S2/S3	G3 Ops(B)/TAC Intel (B)	On occurrence	Voice	FLASH (ZZ)
		Bde/Bn/Co S2/S3 CM&D(S)	G3 Plans(S)/G2	On occurrence	Voice/TTY	
		G3 Plans(S)/G2 Adj Div G2/G3	Corps G3/G2	As obtained	Voice/TTY	App 1
2	Intelligence Summary (STANAG 2022)	Bde S2	Div G2 CM&D Daily	0500 and 1700		
			Corps G2,Major Subord Elm S2's	To Corps NLT 0700 and 1900	TTY/Courier	App 2
3	BOMBREP/SHELREP/MORTREP (STANAG 2008)	Div G2 CM&D(S)	Corps G2, TAC Intel, G2 Plans, A&P, CI&I, G3 Plans, Bde next higher S2/G2 CM&D(S) nearest Arty FSO/FSE	As obtained	Voice/TTY/Courier	App 3
4	Daily Ground Recon/Surveillance Plan/Summary	Major Subord Elm	Div G2 R&S(S)	Due Div daily NLT EENT	TTY/Courier	App 4
5	Joint Tactical Air Recon/Surveillance Request (Preplanned)	Major Subord Elm S2	Div G2 R&S(S)	Due Div NLT 0600 day prior	TTY/Courier	App 5
		Div G2 CM&D(S)	Corps G2 Air	Due Corps NLT 0700 day prior		
6	Joint Tactical Air Recon/Surveillance Request (Immediate)	Requesting S2/G2 CM&D (S)	DASC (Monitored by RACP/TACP(S)	As required	Voice (Air Force Air Request Net)	App 6 not used See App 5
		TAC Intel(B)	DASC (Monitored by TACP(S)			
7	Effective Wind Message	Div Chem Sec FSO(B), Bde FSCC	Bde/DIVARTY/DISCOM/Sep Bns, III Corps, Adj Divs	Every 6 hrs, or every 2 hrs during nuc ops	O&I, TTY, Courier	App 7
8	Unit Rad Dose Status	Bde/Bn/Co S3	G3 (Plans)(S) G3 (Ops)(B)	Daily as of 1800 hrs when required	TTY/Courier	App 8
		G3 (Plans)(S)	Corps G3	NLT 1600 Sat		

ANNEX S (REPORTS) DIVISION TAC SOP

RPT NR	TITLE	FROM	TO	FREQUENCY	METHOD TRANSMISSION	REMARKS
9	Friendly Chemical Strike Warning	Div Chem/G3	Div G3 (Plans)(S) G3 (Ops)(B) Sub S3/G3 and affected units Div FSE, TFS	As required	Voice	App 9 FLASH (ZZ)
10	Nuc/Accident Incident Rpt	Bde S3, Div Arty S3 G3 (Plans)(S)	Div G3 (Ops)(B) G3 (Plans)(S) Corps G3	On occurrence	Fastest means	App 10 FLASH (ZZ)
11	Nuclear Strike Warning	Corps G3, Div FSE G3 (Plans)(S), Div Arty S3	Div G3 (Plans)(S) G3 (Ops)(B) Sub S3/G3 and affected units Div FSE, TFS	As required by proximity to DGZ	Voice/TTY	App 11
12	Front Line Trace	Bde/Sqdn S3	G3 (Ops)(B), G3 (Plans)(S)	As of even hrs due Div NLT every 4 hrs plus 30 min	Voice/TTY	App 12
		G3 (Plans)(S)	Corps G3	To Corps as of 0200 and 1400 NLT 0400 and 1600	TTY/Courier	
13	Hostile Air Attack	Bn/Bde/Sqdn S3 G3 (Ops)(B)	Bde/Div G3 (Ops)(B) G3 (Plans)(S) Affected units	As required	Voice	App 13 FLASH (ZZ)
14	Task Organization	Bde/Sqdn S3	G3 (Ops), G3 (Plans)(S)	Daily NLT 1500 or when changes occur	Voice/TTY/Courier	App 14
		G3 (Plans)(S)	Corps G3	Daily NLT 1600 or when changes occur		
15	Artillery Sit Report	Div Arty S3	G3/FSO(B) G3/FSE(S) Corps Arty S3	Daily as of 2400 Due NTL 0200	TTY	App 15
16	Artillery Position Report	Div Arty S3	Div G3/FSE(S) Corps Arty S3 Div G3/TFS hrs	Daily NLT 0300, 0900, 1500, 2100	TTY	App 16
17	Engr SITREP	Engr Bn S3	G3 (Ops)(B) G3 (Plans)(S) G4 (Ops)(S) Corps [illegible]	Daily as of 2400 Due NLT 0200	TTY	App 17

ANNEX S (REPORTS) DIVISION TAC SOP

RPT NR	TITLE	FROM	TO	FREQUENCY	METHOD TRANSMISSION	REMARKS
18	Bridge Recon Report	Unit performing G3 (Plans)(S)	G3(OPS)(B) G3(Plans)(S) Div Engr Corps G3	As required	TTY/Courier	App 18
19	Ford Recon Report	Unit performing G3(Plans)(S)	G3(OPS)(B) G3(Plans)(S) Div Engr Corps G3	As required	TTY/Courier	App 19
20	Report of Friendly or Enemy Minefield (STANAG 2036)	Discovering Unit/ Bde S3 G3(Plans)(S)	Bde G3(OPS)(B) G3(Plans)(S) CM&D (S) Corps G3	As required	TTY/Courier	App 20
21	Report of Initiation of Laying Minefield (STANAG 2036)	Bde S3 G3(Plans)(S)	G3(OPS)(B) G3(Plans)(S) Corps G3	As require	TTY/Courier	App 21
22	Aero Medevac Request	Requesting Unit	Med Bn	As required	Voice	App 22
23	Aircraft Availability	Bde/Avn Co/Cav Sqdn Div Arty, DISCOM	G3(Plans)(S) DAME(S)	Daily as of 1400 Due Div NLT 1600	TTY/Courier	App 23
24	ADA Fire Unit Status	ADA Bn S3	Div G3(Plans)(S) DAME(S)	Daily as of 1500 and 0300. Due Div NLV 1700 & 0500	TTY/Courier	App 24
25	ECM Support Request	Requesting Unit	G3(S)	As required	TTY/Courier	App 25
26	ASA Support Request	Requesting Unit	G3(S)	As required	TTY/Courier	App 26
27	Joint Tactical Air-strike Request (Pre-Planned)	Bn/Bde S3 G3(Plans)(S)	Bde/Div G3(Plans)(S) Corps G3 Air	Daily NLT 1500 day prior to TOT	TTY/Courier/Voice	App 27
	Joint Tactical Air-strike Request (Immediate)	Requesting TACP	Corps DASC (TACP-F Monitors)	As required	Voice (AF Channels)	All intermediate HQ monitor; silence is is approval
28	Personnel Daily Summary (PDS)	Bn/Bde S1's Div G1 Ops (S)	Bde/Div G1 Ops(S) Corps G1	Daily, as of 2400 Due Div NLT 0500 Due Corps NLT 0900	TTY/Courier	App 28
29	Daily Status Report (DSR)	Bn (TF) and Separate Companies	DISCOM MMA	Daily as of 1200 Due NLT 1600	TTY/Courier/Voice	App 29
30	Bde Support Status Report (SSR)	Brigade S4/FASCO	DISCOM-SOP Info G4(S)	Daily as of 1200 Due NLT 1600	TTY/Courier/Voice	App 30
31	Div Support Status Report (DSSR)	DISCOM	G4(S)	Daily as of 1200 NLT 1800	TTY/Courier/Voice	App 31

ANNEX S (REPORTS) DIVISION TAC SOP

RPT NR	TITLE	FROM	TO	FREQUENCY	METHOD OF TRANSMISSION	REMARKS
32	Brigade Trains Closing RPT (BTCR)	Brigade S4/FASCO	DISCOM SPO Info G4's	ASAP upon closing when changes occur	TTY/Courier/Voice	App 32
33	Div Support Area Closing Report (DSACR)	DISCOM	G4 Info Major Cmds	ASAP upon closing when changes occur	TTY/Courier/Voice	App 33
34	Spot Loss Report (SLR)	Unit having loss	DISCOM MMA Info Gr(S)	Upon critical equipment loss	TTY/Courier/Voice	App 34
35	Contaminated Fuel Report	Unit Discovering Contamination	G3(Plans)(S)	Upon occurrence	TTY/Courier/Voice	App 35
36	NBC 1	BTRY/CO/BN/Bde	G2	Upon occurrence	Fastest Means	App 2 ANNEX F Initial NBC 1 Reports will be transmitted by FLASH precedence. Subsequent NBC 1 and all other NBC reports will be transmitted using IMMEDIATE precedence
37	NBC 2/3	G2	Bde/BN/CO/BTRY	As prepared	Fastest Means	
38	NBC 4	BTRY/CO/BN/BDE	G2	Upon occurrence	Fastest Means	
39	NBC 5	G2	Bde/BN/CO/BTRY	As prepared	Fastest Means	

Appendix C[1]

TACTICAL OPERATIONS SYSTEM (TOS) OPERATIONAL/ORGANIZATIONAL CONCEPT

1. Operational Concept

a. TOS will consist of an integrated set of hardware (computer mainframes, memory units, user input/output devices, etc.), software (computer programs, data base, operating procedures) and personnel (operators and maintenance personnel for hardware and software). TOS will be supported by existing and emerging tactical communications systems. TOS is designed to support commanders and staff elements at battalion, cavalry squadron, brigade, and division.

b. TOS will have the flexibility to support commanders and staff elements in new or changed configurations that result from implementation of new concepts or doctrine.

c. Further definition of system functions and configurations of equipment will allow TOS to support commanders and staffs at corps and corps-related elements.

d. TOS will provide a capability to communicate within echelons of a division, between divisions, and between division and corps using formatted man and machine readable messages. These messages will be used to transmit information, update data bases, retrieve information from a data base, and perform special processing of data within the data base.

e. TOS will be able to exchange data under controlled conditions with other cooperating tactical data systems, as described in the INTEROP IIIa study.

f. TOS will be able to provide continuous support in a secure manner, in accordance with the guidelines contained in the ATACCIS Surety Handbook.

g. Operational requirements for TOS components are as follows:

(1) Division Computer Center (DCC). Primary use of the DCC is maintenance of the user data base, numerical calculations, filtering, correlation of information, generation of responses to user queries, automated dissemination functions, and support of user-related requirements. The DCC includes a computer mainframe

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[1] This draft Operation/Organizational Concept was provided by the U.S. Army Combined Arms Training Agency, Fort Leavenworth, Kansas.

which is the main computational and memory capability of TOS. TOS users at division main will be able to interact with the DCC directly by cable/wire. Remote TOS users will use the tactical communications system to interact with the DCC.

(2) Operator Control Console (OCC). The OCC is co-located and connected directly to the DCC. This console provides a means for hardware control, control and monitoring of input/output operations and enemy jamming, and for monitoring, controlling, and/or modifying the technical status of the overall system.

(3) Terminal Control Unit (TCU). This is a small-scale computer system, with memory, that allows TOS users to interact with the DCC, with various other devices within TOS, with other systems, and with outside agencies. The TCU is the controller for the Analyst Consoles (AC) and the Interactive Display System, when required. With built-in processing capability and memory, the TCU can freely and rapidly exchange data with the DCC, and must provide the capability to receive, prompt, process data, retrieve, compose, edit, validate, store, display, print, transmit, net monitor digital/voice messages and interface with Army tactical communications equipment/systems. The TCU will also provide an interactive capability to create, store, retrieve, transmit, and receive graphic displays. A stand-alone capability is necessary for short-term CONOPS requirements.

(4) Analyst Console (AC). The AC is the primary user device for the display of, and interaction with, computer-stored data. Interaction with the central data base of the DCC is through the TCU. Analyst Consoles are coupled directly to the TCU and should be equipped with a display/keyboard combination for creating, reviewing, and graphically portraying information of interest to the user, and printers for hardcopy output. Capabilities of the AC should also include the ability to review, store, manipulate, and disseminate data, both on request (in form of a query), or automatically. The AC must have a screen capable of portraying alphanumerics and graphics on an illuminated map background.

(5) Interactive Display System (IDS). The IDS provides the large display capability for presentation of decision information to the commander. It consolidates efforts from other IDS and from each analyst's console operator. The IDS will be a computer-driven display panel approximately 1 meter square. It will provide a map background, capability to create new displays interactively, display information from the data base through direct communication with the DCC or indirectly through connection with a TCU, update the data base from user input, and store/retrieve displays. The IDS operator(s) will have the capability to create unique patterns, lines, and special effects to portray the battlefield for his area of interest. Sufficient memory to store display symbology for use in conjunction with standard military maps is necessary to provide a man-machine interactive capability to reduce the burden on the host computer.

(6) Battalion Input/Output Device (BIOD). This will be a small man-transportable device capable of sending and receiving alphanumeric messages through communication with a TCU or the DCC. The BIOD will provide capability to prompt message composition, edit messages, and allow input/output in either formatted or free text. The BIOD will allow input of operational and intelligence information to brigade/division, and receive responses to SRI's or receive other tactical information deemed appropriate by higher headquarters.

2. Organizational Concept

a. TOS components will be located at division main, division TAC CP, brigade, battalion, and cavalry squadron level. The DCC's and OCC's are employed at division main. AC's, IDS's and TCU's are employed at division and brigade level. BIOD's will be employed at battalion/cavalry squadron level.

b. TOS Personnel Requirements. The personnel listed below represent an increase over current division authorization. These personnel are the only increases necessitated by TOS. Fielding a TOS is not envisioned to decrease current personnel authorizations, but will increase overall operational effectiveness. The manning indicated is tentative, pending preparation of the Provisional Qualitative and Quantitative Personnel Requirements Information (PQQPRI). The computer center section is responsible for maintaining TOS 24-hours per day.

POSITION	GRADE	QUANTITY
System Controller	04	1
Data Processing NCO	E8	1
ADP Machine Operator	E6	2 (1 per shift)
ADP Repairman	E5	2 (1 per shift)
Communications Specialist	E4	2 (1 per shift)
Powerman	E4	2 (1 per shift)

(1) System Controller (SC). The System Controller will have an AC to monitor and control the data base, start and stop the system, query the status of the system, and alter priorities as well as the existing processing schedule. The SC represents the commander whose organization and staff are supported by the DCC, manages the overall ADP system operations, and supervises computer center personnel.

(2) Staff elements which use peripheral devices of the ADP support system will insure that trained operators for the devices are provided from within their assigned staff.

(3) Watch officer positions will be established as additional duties in both the intelligence and operations elements of the

Division TOC to oversee ADP requirements within their respective area. Watch officers, as file managers, are responsible for monitoring and controlling the status of their user files and will coordinate with the system controller on the user related aspects of the ADP system.

c. Division TOS ED System Configuration/Users.

(1) Intelligence Element. The following describes how functional areas within the Intelligence Element will interact with TOS to perform assigned missions.

a) Reconnaissance and Surveillance (R&S). Accomplishes the function of planning and coordination both air and ground reconnaissance and surveillance activities throughout the division and providing information and intelligence thus collected. Personnel performing R&S functions will be provided one AC.

b) Mission Management and Dissemination (MMD). Performs the function of coordinating the flow of all intelligence related information for the G-2 section and attachments by managing the overall collection effort, receipt and dissemination of information and the overall intelligence production effort. Personnel performing the MMD functions will be provided one AC.

c) G-2 Watch Officer. The G-2 Watch Officer has one dedicated AC to perform the functions required as the ENSIT file manager.

d) Analysis and Production. The G-2 analysis and production function is provided one AC which will be used to query TOS ENSIT files for information which will be fused with sanitized intelligence data and provided to G-2 staff members and to decisionmakers at the TAC CP.

(2) Operations Element. The following describes how functional areas within the Operations Element will interact with TOS to perform assigned missions.

a) G-3 Watch Officer. The G-3 Watch Officer has one dedicated AC to perform the functions required as the FRENSIT file manager.

b) Operations. The G-3 operations function is provided one AC to monitor combat operations, develop and coordinate detailed tactical planning for the division, and consolidate, coordinate, and approve all preplanned tactical airstrike requests.

c) Plans. The G-3 plans function is provided one AC to develop operations plans and orders, transmit graphic displays of proposed courses of action to the TAC CP for evaluation, and transmit approved plans to subordinate units for implementation.

d) FSE. The FSE is furnished one AC which will interoperate with the TACFIRE system. The FSE will coordinate data requirements and procedures between TOS and TACFIRE.

(3) Administration/Logistics Element. The G-1 and G-4 plans function will each be provided one BIOD to input personnel, administrative, and logistics information to the TOS data base in support of operations and intelligence planning/analysis, and to provide information of an immediate nature to the DTOC and TAC CP as required.

(4) TAC CP. The Tactical Command Post will be provided with an AC, an IDS, and a TCU. The AC will allow interaction with the G-2/G-3 staff elements at division main as well as any other echelon having an I/O capability within TOS. The commander and his G-2 and G-3 will be able to receive and transmit reports and messages via the TCU. The large screen IDS will enable the commander, G-2 and G-3 to review graphic displays and make a rapid assessment of the tactical situation, initiate corrections if required, and prepare sound recommendations and decisions based upon complete and factual information.

(5) Brigade. The brigade will be provided one TCU and three AC's. The TCU will control the three AC's which will be allocated as follows:

a) S-2. The S-2 AC will interact with division and subordinate battalions, perform hierarchical review, limited correlation and filtering, and pass primarily combat information, with some intelligence, to higher headquarters.

b) S-3. The S-3 AC will provide graphic and alphanumeric interaction with the operations element and the TAC CP at division and interaction with subordinate battalion BIOD's.

c) BICC. One AC will be furnished to the S-2 BICC to accomplish intelligence analysis, some correlation and filtering, coordinate with the division intelligence element, perform intelligence collection management activities, and establish standing requests for information to satisfy requirements outlined in FM 100-5.

(6) Battalion. The battalion will be furnished one BIOD to

input -- in either formatted or free text alphanumeric form -- intelligence and operational information to brigade/division, and receive responses to SRI's or other tactical information provided by higher headquarters.

(7) Cavalry Squadron. The squadron will be furnished one BIOD to accomplish the same functions listed for the battalion.

(8) Stand Off Target Acquisition System (SOTAS). SOTAS ground stations will be provided one TOS/BIOD to accomplish systems interface, and provide for data input to the intelligence and operations elements in the DTCC, and respond to SOTAS tasking by the G-2.

(9) Technical Control and Analysis Center (TCAC). The TCAC will be furnished one TOS BIOD which will, based on tasking received, provide sanitized ELINT and SIGNIT type intelligence to the DCC.

Appendix D

MULTIOBJECTIVE LINEAR PROGRAMMING

Multiobjective linear programming differs from linear programming because it deals with more than one objective function. A basic linear programming problem is of the form:

$$\text{Max } Z = \bar{c}^{\,t}\bar{x} \quad \text{subject to } \bar{A}x \leq \bar{b}, \quad \bar{x} \geq 0 \tag{1}$$

where Z is a scalar; $\bar{c}$ is an n x 1 vector, and c_j, an element of $\bar{c}$, is in \$/unit of x_j; $\bar{x}$ is an n x 1 vector of decision variables comprised of scalars x_j; $\bar{A}$ is an m x n matrix; $\bar{b}$ is an m x 1 vector and b_i is in units of resource; and all quantities except the x_j and resultant Z are known. A general multiobjective problem with s objectives is, however:

$$\text{Max } \bar{Z} = \overline{Cx} \quad \text{subject to } \overline{Ax} \leq \bar{b}, \quad \bar{x} \geq 0 \tag{2}$$

where all parameters are as before except that $\bar{Z}$ is an s x 1 column vector and $\bar{C}$ is an s x n matrix. It is clear from Equations (1) and (2) that the two problems are identical except for their objective functions.

Although the normal linear programming problem is easily solved using well-known techniques such as the simplex method, the multiobjective problem is not easily solved because $\bar{Z}$, a vector, cannot be immediately maximized or minimized. Clearly, a normal linear programming problem would result if all but one of the objectives was ignored. For example, in the problem

Maximize dollar savings

subject to technological

constraints

other constraints

an optimum may be found (point D in Figure 1). When considering both savings and information impacts, however, little can be said about the optimum when looking at the system without preference information. We can only say that this optimum lies somewhere on the transformation curve of net benefits. The two-objective problem can be stated as

Max (savings benefits + information completeness benefits)

subject to technological constraints
other constraints.

Such a two-objective maximization problem may be written mathematically as:

$$\begin{aligned} &\text{Max } \overline{Z} = \left[Z_1,\ Z_2\right]^t = \overline{Cx} \\ &\text{subject to } \overline{Ax} \le \overline{b} \\ &\qquad \overline{x} \ge 0 \end{aligned} \tag{3}$$

where $\overline{C}$ is now a 2 x n matrix and $\overline{x}$, $\overline{A}$ and $\overline{b}$ are defined as before. Note that the constraint set defined by $\overline{Ax} \le b$ on n-space maps into the feasible region defined by $\overline{Z}$ on 2-space as shown in Figure 1. The boundary of the feasible region is, of course, the transformation curve, TC.

For single objective linear programming, optimality is unambiguous. That is, $\overline{x}^* \epsilon X$ is optimal when maximizing if:

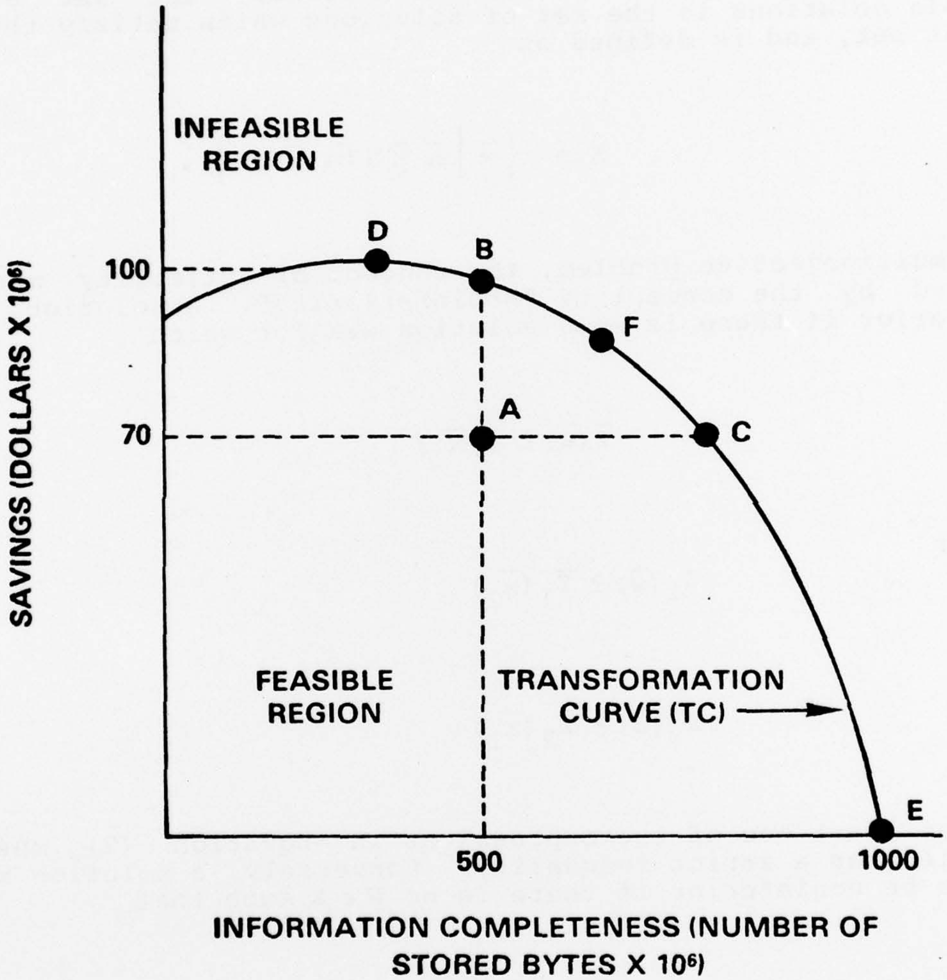

Figure 1. Graphical Representation of a Multiobjective analysis

$$Z(\overline{x}^*) \geq Z(\overline{x}) \text{ for all } \overline{x} \epsilon X, \ \overline{x}^* \epsilon X$$

where X is the set of all feasible solutions. The set of all feasible solutions is the set of solutions which satisfy the constraint set, and is defined as

$$X = \left\{ \overline{x} \,\middle|\, \overline{A}\ \overline{x} \leq \overline{b},\ \overline{x} \geq 0 \right\} . \qquad (5)$$

For a multiobjective problem, the concept of optimality must be replaced by the concept of "noninferiority". A solution, $\overline{x}_1 \epsilon X$, is inferior if there is some solution $w \epsilon X$ for which

$$\overline{Z}(\overline{w}) \geq \overline{Z}(\overline{x}_1) \qquad (6)$$

that is

$$Z_1(\overline{w}) \geq \overline{Z}_1(\overline{x}_1)$$

and

$$Z_2(\overline{w}) \geq Z_2(\overline{x}_1) \qquad (7)$$

where at least one of the expressions in Equation (7) must be satisfied as a strict inequality. Conversely, a solution $\overline{x}^*_1$ is said to be noninferior if there is no $\overline{w} \epsilon X$ such that

$$Z(\overline{w}) \geq \overline{Z}(\overline{x}^*_1) . \qquad (8)$$

Whereas the solution of a single objective linear programming problem is the optimal solution, the solution of multiobjective linear programming is the definition of the set of noninferior solutions, otherwise known as the noninferior set.

The desired set of noninferior solutions will always lie on the boundary of the feasible region. As one sees in Figure 1, any interior point, like point A, of the feasible region will be inferior to at least one boundary point, such as points B and C. It is important to realize that all the transformation curve need not be in the noninferior set. Note that in Figure 1, the portion of the transformation curve between the vertical axis and point D is inferior to point D.

It is possible to solve a multiobjective linear programming problem, that is, generate the noninferior set, by first transforming the vector-valued objective function into a scalar-valued function which allows solution by conventional methods. The solution of the transformed problem will give a point in the noninferior set. The parameters used in the transformation may then be varied systematically to provide enough additional points to represent the noninferior set. One of the first presentations of multiobjective linear programming was given in Beeson.[1]

Two approaches to the transformation of the objective function into a scalar quantity are the so-called weighting method and the constraint method. Weighting techniques have been described by Zadeh,[2] Savir,[3] Geoffrion,[4] and Kapur.[5] These approaches transform the two-dimensional problem of Equation (3) into

$$\text{Max} \sum \lambda_i z_i = \lambda_1 z_1 + \lambda_2 z_2 \qquad (9)$$

$$\text{subject to } x \in X$$

where the objective function is now a scalar quantity. Generally one of the λ_i will be selected to be equal to unity, thereby specifying objective i as the numeraire. All other objectives are weighted by selected λ's in terms of the numeraire.

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[1] Beeson, R., Optimization with Respect to Multiple Criteria. Ph.D. Thesis, Los Angeles:University of Southern California. 1971.
[2] Zadeh, L. "Optimality in Non-Scalar-Valued Performance Criteria". IEEE Transactions on Automatic Control , Col. AC-8. 1963.
[3] Savir, D. Multiobjective Linear Programming. Report ORC 66-21. Berkeley: Operations Research Center, University of California. 1966.
[4] Geoffrion, A. "Solving Bicriterion Mathematical Program." Operations Research , Vol. 15. 1967.
[5] Kapur, K. "Mathematical Methods of Optimization for Multiobjective Transportation Systems." Socio-Economic Planning Sciences Vol. 4. 1970.

When the noninferior set is strictly convex, it may be easily generated by the weighting method. By successively solving the transformed linear programming problem of Equation (9), with systematically varied values of the λ_i weights, one may trace out the noninferior set. This procedure is very easy to carry out using the parametric programming features available in most linear programming computer packages.

If the noninferior set is not convex, the weighting method will fail to generate the entire noninferior set. Figure 2 shows a transformation curve, defining a noninferior set which is not convex. The solution procedure, using the weighting method, is started with $\lambda_1 = 0$, $\lambda_2 = 1$, and yields the solution point A. Next, the value of λ_1 is increased to $\hat{\lambda}_1$. The solutions so obtained are on the segment AB of the transformation curve. When $\lambda_1 = \hat{\lambda}_1$, however, three possible solutions exist, no one of which is better than the others. The solution procedure continues by increasing λ_1 to values greater than $\hat{\lambda}_1$, giving solutions on the segment DE of the noninferior set. The key point is that the solutions "skip" from the segment AB to the segment DE, excluding the segment BD of the noninferior set. That is, the weighting method fails to generate the entire noninferior set when it is nonconvex.

An approach that will generate the whole noninferior set, including nonconvex shapes, is the constraint method which was first described by Facet.[6] In this solution procedure, the original problem of Equation (3) is transformed into

$$\text{Max } Z_2$$

$$\text{subject to } \overline{x} \in X \qquad (10)$$

$$Z_1 \quad B_1.$$

The objective function in Equation (10) has been made scalar by the simple artifice of including objective Z_1 as a constraint in the problem. The subsequent approach for generating the noninferior set is nearly transparent. B_1 is set equal to zero or some

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[6] Facet, T. "A Solution to the Multiobjective Linear Programming Problem". Cambridge: Ralph M. Par Laboratory Report, MIT. 1970.

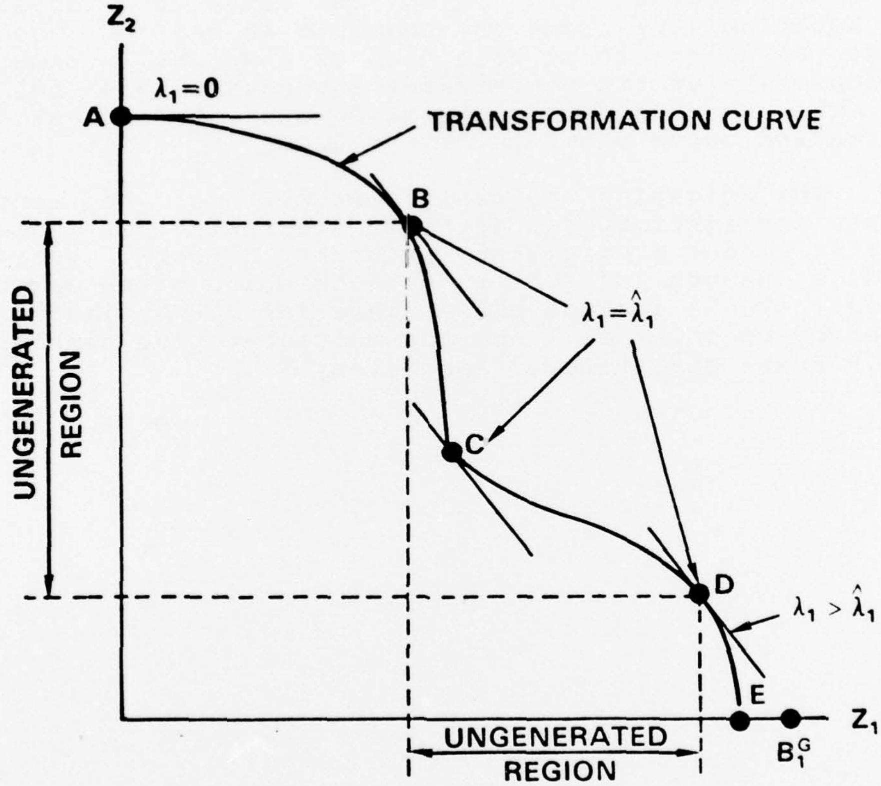

Figure 2. Weighting and Constraint Methods with a Nonconvex Noninferior Set

other predetermined lower bound and is then increased incrementally until a solution is obtained which is infeasible. Each value of B_1 solves the scalar problem, thereby yielding a point in the noninferior set. For example, in Figure 2, B_1 is varied from zero to B_1^G, where there is no feasible solution to Equation (10).

A shadow price λ_1, is, of course, associated with the constraint $Z_1 \geq B_1$ in Equation (10). Consequently, at every solution point of Equation (10), λ_1 is the value of the trade-off of objective Z_2 against Z_1. Also, the value of λ_1 obtained from solving Equation (10) along the segments AB and DE would yield the same solution if it were used as a weight in Equation (9). The nonconvexity of the noninferior set causes this relationship between the two problems to break down on the segment BD of the transformation curve shown in Figure 2.

The weighting and constraint methods are conceptually the most straightforward methods available for solving multiojbective linear programming programs. Recent research has produced a number of other methods which offer computational advantages. These include the noninferior set estimation method developed by Cohon et al.[7] and the multiobjective simplex methods of Holl,[8] Evans and Stever,[9] and Zeleny.[10]

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[7] Cohon, J., Church, R. and Sheer, D. "Generating Multiobjective Trade-offs: 1. An algorithm for Bicriterion Problems." Water Resources Research, forthcoming.

[8] Holl, S. "Efficient Solutions to a Multicriteria Linear Program with Applications to an Institution of Higher Education". Ph.D. Thesis. Baltimore: The Johns Hopkins University. 1973.

[9] Evans, J. and Stever, R. "A Revised Simplex Method for Linear Multiple Objective Programs." Mathematical Programming, Vol. 5. 1973.

[10] Zeleny, M. Linear Multiobjective Programming. Berlin: Springer-Verlag, 1976.

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